

AERO DIGEST

AVIATION ENGINEERING

JULY 1956

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progress of missile science



Let Freedom Ring!

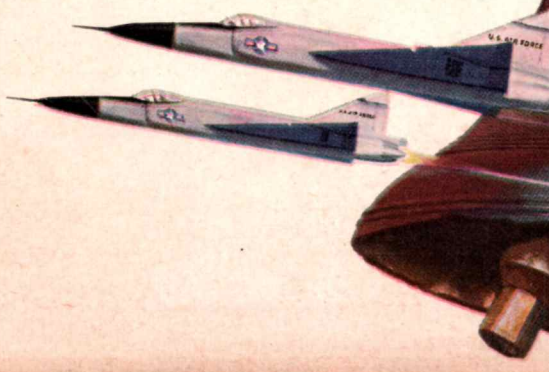
From the moment the *spirit of '76* was born with the *shot heard 'round the world* and proclaimed with the ringing of the Liberty Bell... sounds have played a *vital* part in our American freedom!

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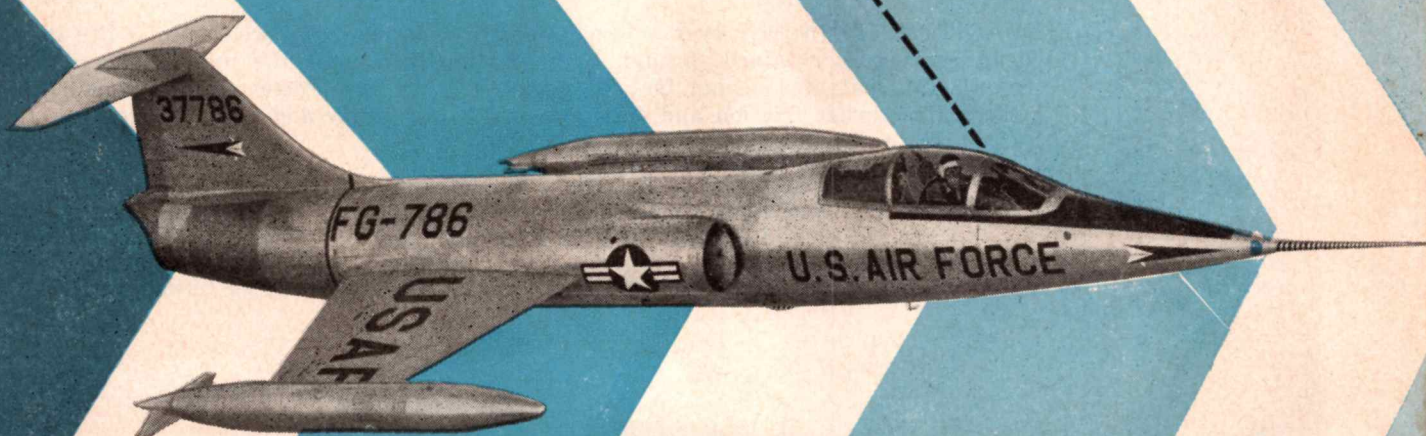
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IN THE LOCKHEED F-104A STARFIGHTER



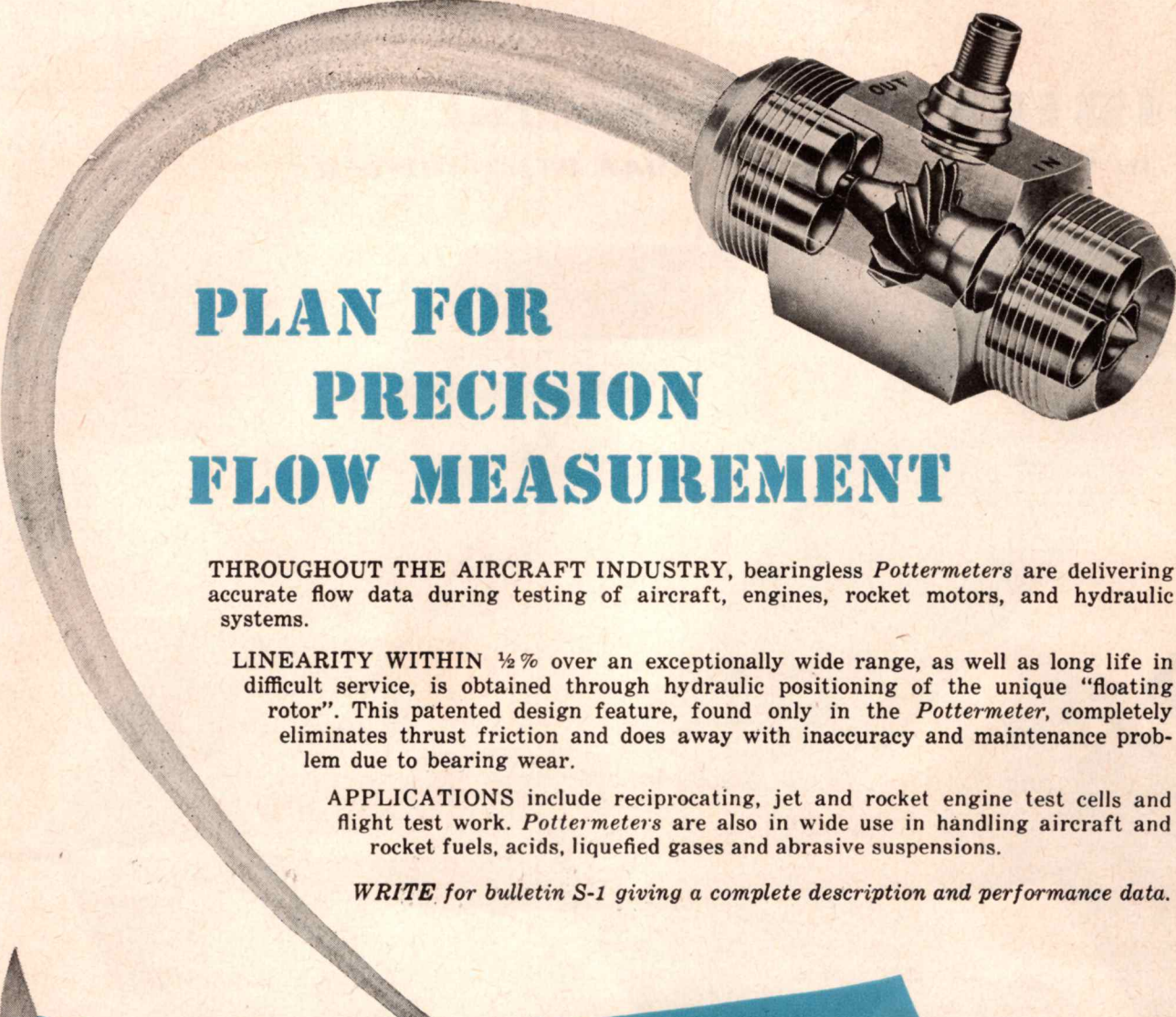
Hailed as the "world's fastest combat plane," the top speed of the new, supersonic F-104A Starfighter is still "Confidential Information."

This speed, where fractions of seconds count in combat, required specially designed windshields and canopy to give greater visibility for the pilot. Because of the critical optical requirements, their production was logically entrusted to Swedlow's specialized skill and experience in plastic enclosures.

Swedlow
PLASTICS CO.

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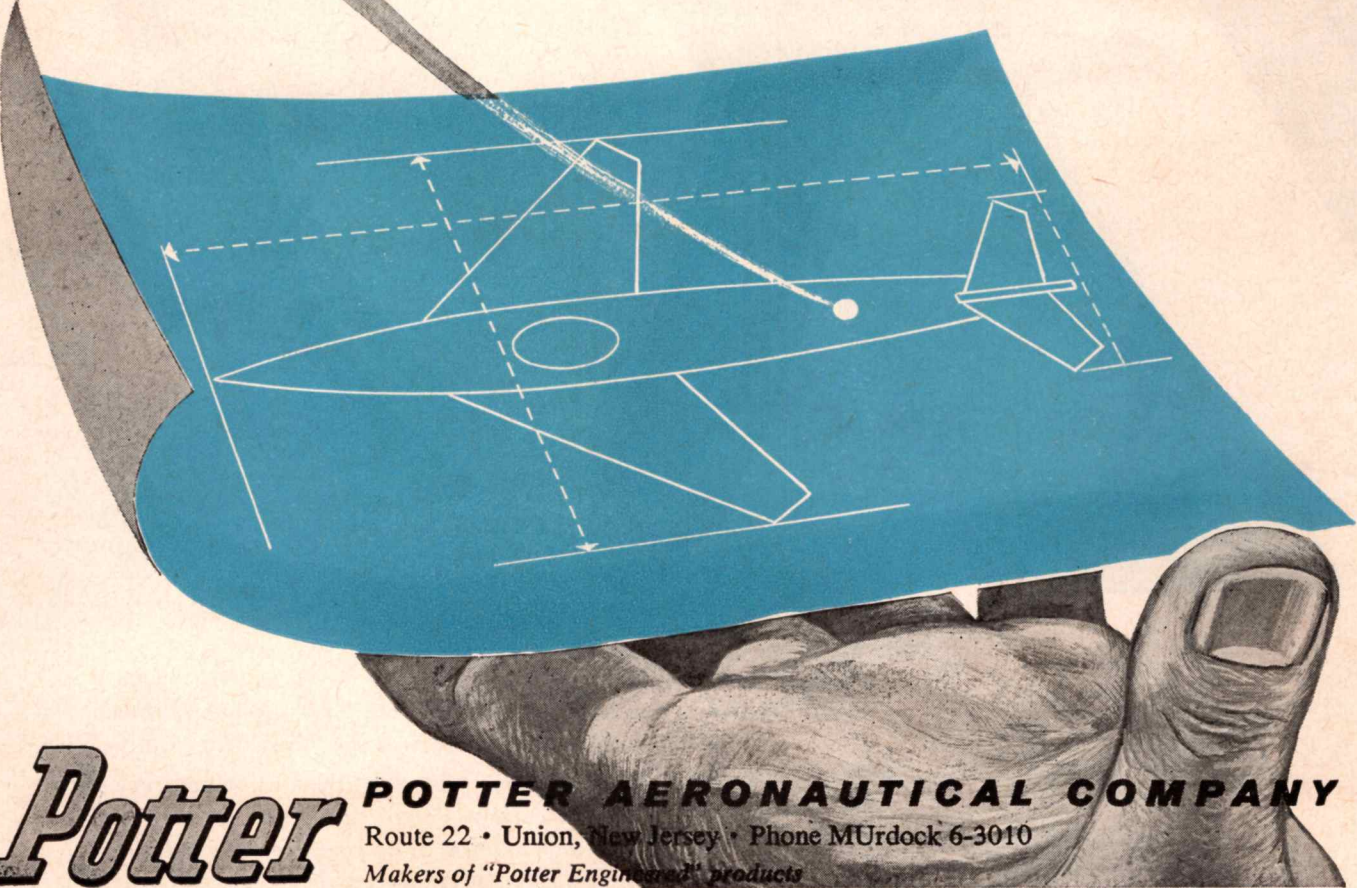
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Makers of "Potter Engineered" products

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MISSILE ENGINEERING

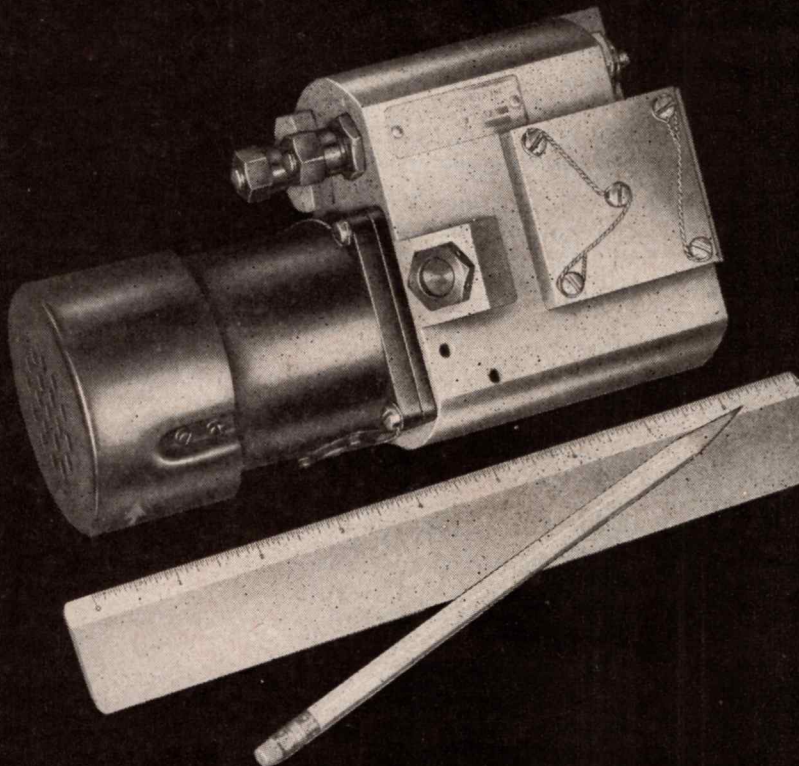
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Unit consists of: positive-displacement pump, electric motor drive, oil reservoir, expansion chamber, porous bronze ten-micron filter, pressure regulating valve, filter relief valve, and expansion relief valve.

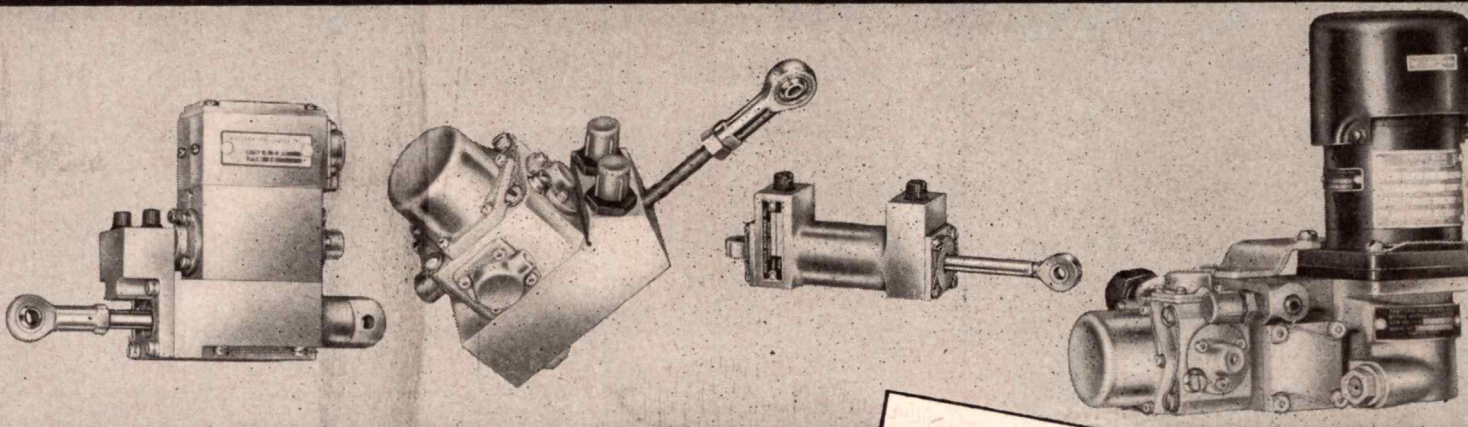
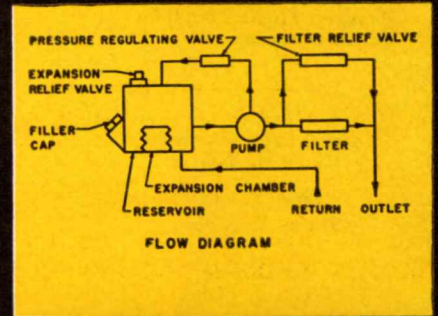
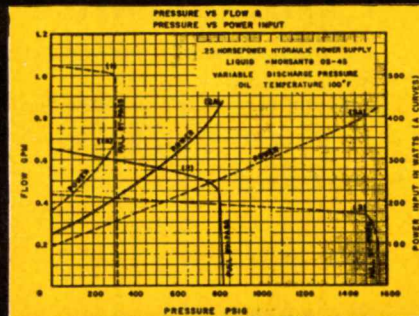
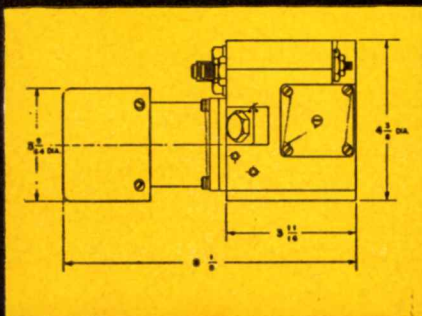
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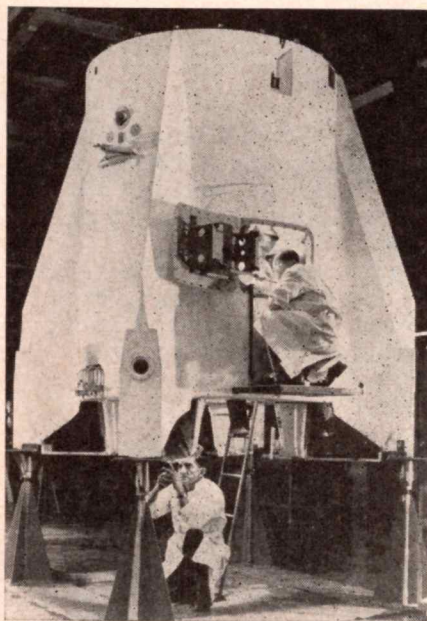
aero news digest

News in Brief

Underwater-to-surface and underwater-to-air guided missiles that can be launched from submarines (Aero Digest, p. 5, June 1956) are under study and development by Hughes Aircraft.....Republic Aircraft is courting experienced missile engineers in order to expand the company's missile program. It is reported that the company is interested in ICBM development and is giving the nod to solid rather than to liquid propellants as a power source.....The Navy's preference for solid rocket propellants as against liquid because of simplified logistics is worrying some of the liquid propellant manufacturers. They are quick to point out, however, that only through using liquids can entire in-flight missile guidance be controlled.....Bill Lear says that today's big market for aircraft instruments for business aircraft is in Europe. It appears that most of the business flying there is still by-seat-of-the-pants navigation..... Hughes Aircraft experience in the Arctic points up three musts for electronic maintenance under cold conditions: fasteners amenable to quick connect and disconnect, built-in test equipment, and accessibility.The Grand Central Rocket Company of Redlands, California, developer and manufacturer of solid rockets and holder of a contract for producing the third-stage rocket for the Project Vanguard satellite needs many types of engineers for their enlarged program. For more information write to L. Thacker at Grand Central. The company states that theirs is the only plant designed and built exclusively for solid propellant rockets. They also say that they are at present test firing the Vanguard third-stage rocket.Franklin C. Wolfe Company, Culver City, claims that some of their O-Seals, guaranteed against fuel leakage up to 350°F. have successfully withstood temperatures of 550°F.....Ground handling of the DC-8 will be almost the same as handling the DC-7, according to Douglas engineers. Most major airports will need only minor changes in facilities to accommodate the new jetliner.....The Douglas DC-7 and Boeing 707 are strikingly similar in physical appearance, except for a 30° wing sweepback for the Douglas craft and a 35° wing sweepback for the Boeing. Although the larger sweepback may give the Boeing 707 a slightly higher top speed, Douglas claims that the lesser sweepback will result in piloting techniques close to those used in today's commercial airliners.....Marquardt Aircraft reveals that it is building a new plant in Ogden, Utah, with target date for completion being the summer of 1957. Development and manufacturing jobs for engineers are open in this plant which is expected to house 4000 personnel. Hiring is going on for home plant indoctrination. Write Robert Welch, Marquardt Employment Office, Ogden, Utah for more information.....Cornell Aeronautical Laboratory, Inc. has been awarded a Boeing Airplane



Anthropomorphic dummy ejected from Project Smart sled.

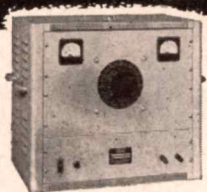


Wiring a Redstone missile tail.

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UNIT: 0-125 VOLTS

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speed, displacement and with
counters or control devices.

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small space and light weight
requirements in airborne de-
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cations where space and low
cost are essential.

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temperatures up to 500° F. Use-
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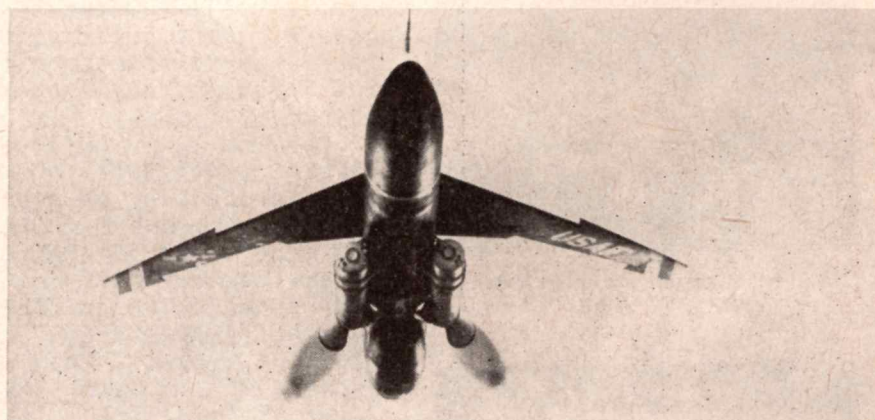
4501-AD North Ravenswood, Chicago 40, Ill.
Canada: Atlas Radio Ltd., Toronto

For further information
circle Reader Reply No. 25

Company contract for a new study of titanium. The one-year program will investigate the strength characteristics of the high-temperature, corrosion-resistant metal. Information from these studies will be applied to the design of supersonic aircraft. . . . Berkeley division of Beckman Instruments will build the biggest analog computer ever assembled west of the Mississippi for General Motor's Allison division. When completed, the computer will stand six feet high and span a width of nearly 60 feet. The computer will be used to simulate jet engines electronically. . . . Should you be in Switzerland working on aircraft instrumentation, and be approached by a big fellow who announces he is ex-King Michael of Romania, don't be surprised. He's heading up an aircraft instrumentation school in Switzerland for Bill Lear. Bill Lear, Jr. will soon be there too.

SM-62 Snark Unveiled

Little noted by the press was the fact that Northrop's SM-62 Snark ICBM, the Air Force's first long-range missile to be test flown, for the first time put to practical use in a missile the long-heralded elevons. The surface-to-surface winged pilotless bomber, designed to deliver a nuclear warhead over intercontinental distances, has a long slender fuselage, sharply pointed nose, swept wing and a tail consisting only of a vertical stabilizer. Its thin wings feature a "saw tooth" leading edge and elevons—a combination of ailerons and elevators on the trailing edge. These eliminate the need for a horizontal tail. The missile is 74 feet long, has a wing spread of 42 feet

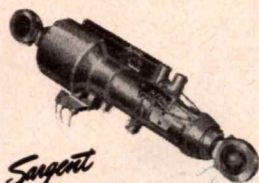


Northrop SM-62 Snark

and is approximately 15 feet high. During launchings, the Snark obtains its initial acceleration from two booster rockets attached to the fuselage, which are ejected after use. This missile is powered by a Pratt & Whitney J-57 turbojet engine. A number of successful launches of the Snark have been conducted at the Air Force Base Missile Test Center, Patrick Air Force Base, Fla. Produced by Northrop Aircraft, Inc., in its main plant at Hawthorne, Calif., the project was initiated in March, 1946.

55-G Missile Test Stand

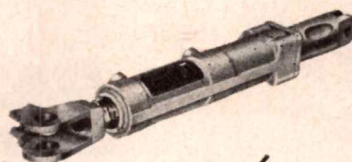
A new electro-hydraulic shaker, "Earthquake Ernie," is aiding missile reliability testing at Northrop. Originally used to check out the company's Snark missile, the box-like device, which measures less than one cubic foot in volume, was developed to test the effects of frequency vibrations ranging from 5 to 600



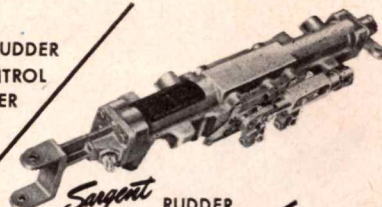
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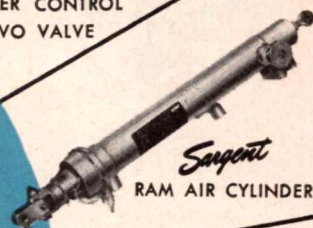
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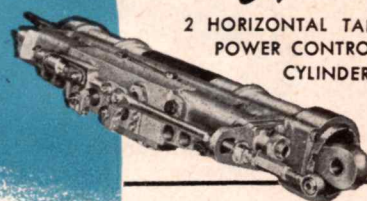
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JULY 1956

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JAPAN AIR LINES



PRATT & WHITNEY ENGINES HELP BUILD U.S. LEADERSHIP IN JET LINERS

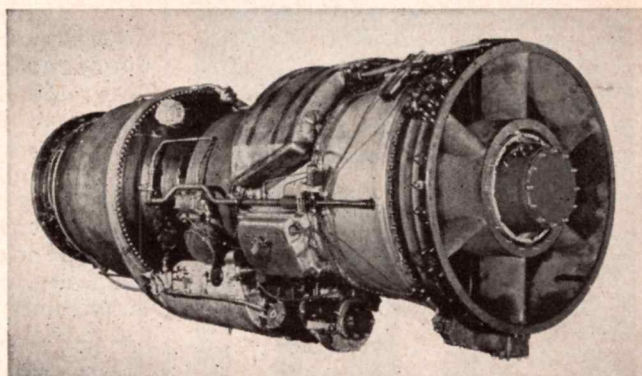
***16 leading airlines will offer jet service
in U. S. transports with JT3 and JT4 engines***

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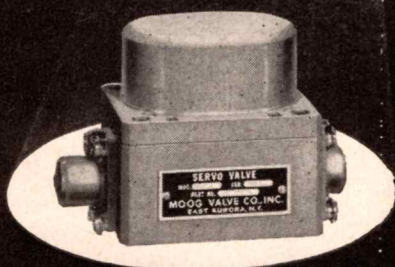
PRATT & WHITNEY AIRCRAFT JT3 ENGINE, civil aviation's version of the widely-used military J-57, most powerful jet engine now in quantity production.

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EAST AURORA, N.Y.

For further information
circle Reader Reply No. 43

cps on airframe sections housing sensitive electronic equipment. During tests the specimen can be subjected to a force of more than 55 G's. Northrop engineers, realizing that unknown vibrations on takeoffs were causing excessive strain, especially on pilotless aircraft electronics, invented "Ernie" to simulate conditions encountered on a missile launch so that vibration effects on full-system components could be recorded prior to actual flight. Heart of the device is a two-stage electro-hydraulic servo built by the Bertea Products Co., Pasadena, Calif. This valve allows the needed precision control of the hydraulic power. "Earthquake Ernie," which has a one-quarter inch stroke, ran through more than 120-million cycles—equivalent to 500 miles continuous operation—on its first test schedule without requiring rework or a change in parts. The device is mounted on a 10,250 pound lead weight, which adequately resists the thrust of its vibration action and allows almost 100 percent of the motion to be transmitted directly to the specimen being tested.

Japan Wants Missiles

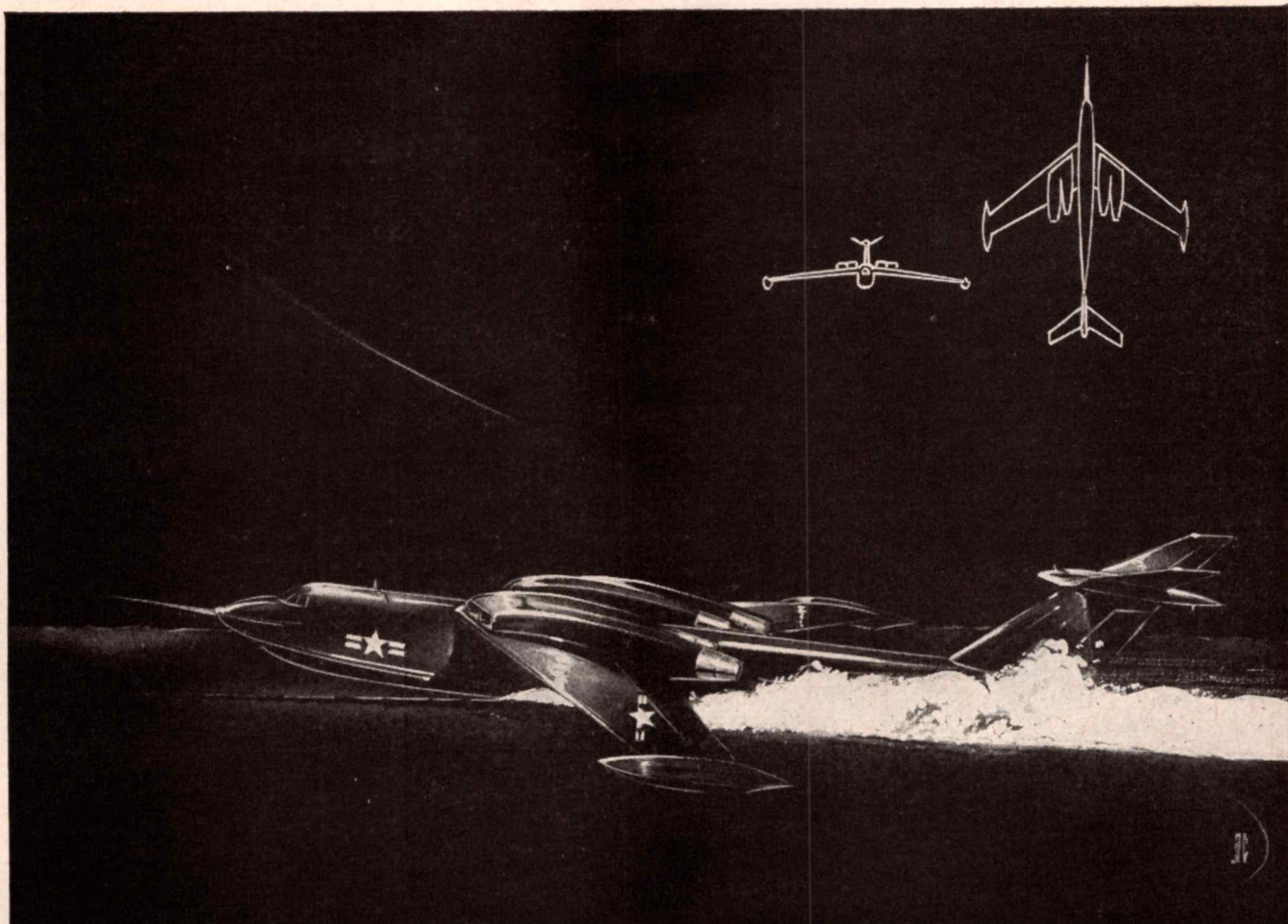
The Japanese National Defense Agency (NDA) is in the market for 400 80-mm caliber air-to-air rockets and two airborne launchers for use by F-86F Saberjets. It is reported that the Agency is likely to select Swiss-Oerlikon guided missiles, which will be used for research and for the ultimate establishment of a Japanese guided missile industry.

Heat-Test Facility for Hypersonic Missiles

Paving the way for further progress in its developments of guided missiles, McDonnell Aircraft Corporation has started operating a unique facility for full-scale structural testing of missile components. The facility duplicates the extreme heat conditions that are met by missiles traveling at more than 5000 miles an hour. A missile specimen 15 feet long and 3 feet in diameter can be tested at temperatures up to 1000 °F, and smaller structures can be subjected to tests at temperatures up to 1500 °F. The method adopted is a radiant-heat system using quartz lamps and heat reflectors. This system allows wide flexibility to be obtained since the number of lamps used, the distance between the missile specimen and the lamps can be adjusted to get a higher or lower rate of heating. The engineers report that this method of structural testing is a significant improvement over conventional testing, since it more closely duplicates flight conditions through the simultaneous application of flight loads and extremely high temperatures to the basic structures.

British Fireflash in Full Production

The first British air-to-air guided missile designed to destroy radio-controlled planes is in production for the Royal Air Force and under consideration by NATO. Named the Fairey Fireflash, it is carried by a piloted aircraft, propelled to supersonic speed by solid-fuel rockets, and has a warhead designed to explode as soon as it is within lethal range of the target. According to the British Minister of Supply, a version of the Hawkes Hunter fitted with the Fireflash will be available for export. The missile, which is being



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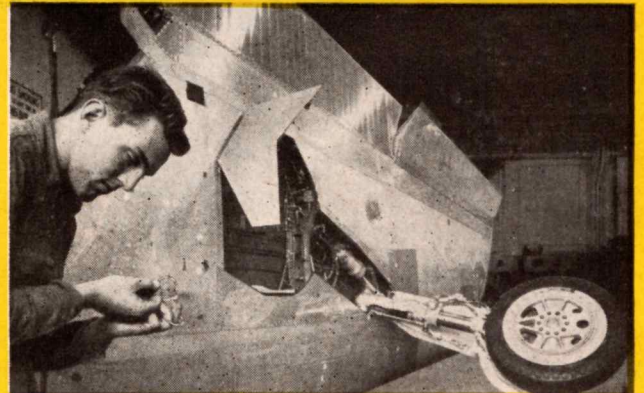
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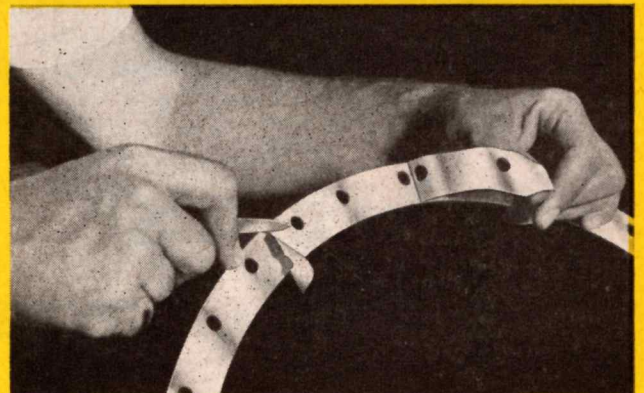
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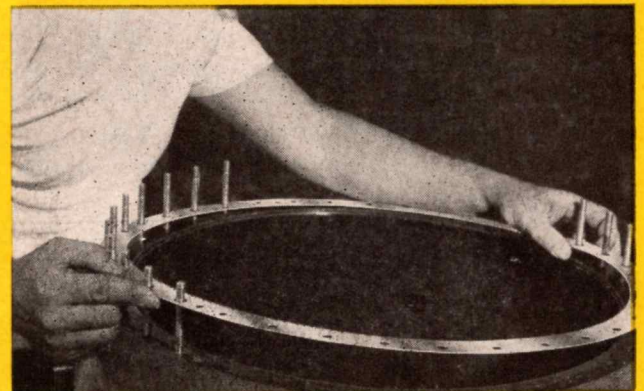
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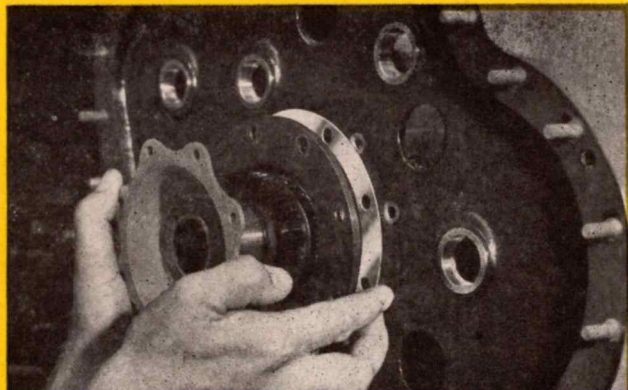
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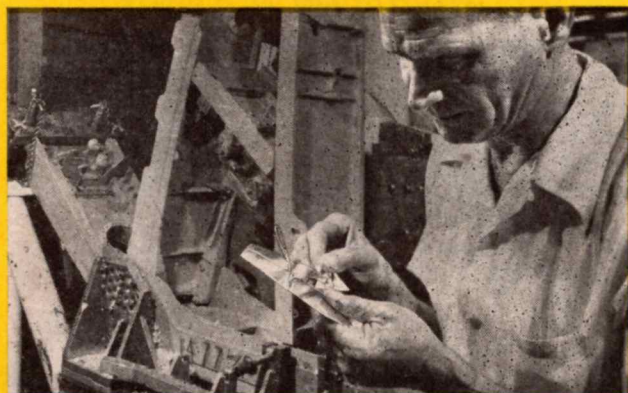
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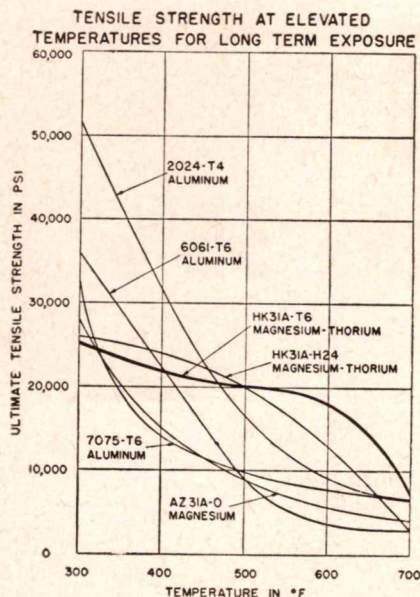
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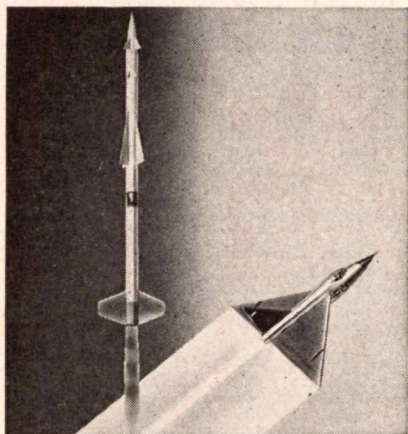
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disclosed Project Smart (Supersonic Military Air Research Track), built and operated for the U. S. Air Force Wright Air Development Center, may soon give answers to critical questions. Five high-priority studies are docketed: (1) Do the steps in the escape sequence function properly under actual, full-scale conditions? (2) What are the linear and angular accelerations encountered during escape? (3) What are the loads produced in the various components of the escape system? (4) Does the ejected seat or capsule clear the aircraft structure? (5) Is there adequate protection from air-blast and other high speed aerodynamic effects?

New Martin Matador Test-Fired

The Martin Company has announced that successful test firings have been made with a new version of the Martin Matador tactical missile, known as the TM-61P. The new missile is longer and carries a larger nose section than present USAF TM-61 Matadors. TM-61B test firings have been performed at the Air Research and Development Command's Holloman Air Force Base in New Mexico. For tactical missions, the TM-61B will be given an entirely new airborne guidance system.

Inertial Guidance for Advanced Missiles

AC Spark Plug Division of General Motors has revealed that it is developing an inertial guidance system for an "advanced missile" for the Air Force. The basic concept is that the missile must be accurately guided to the target without aid from radar, radio or any ground or celestial reference. Once the correct latitude and longitude of the launching and target points have been set into the missile guidance system, the missile is on its own. Since it uses no radar or radio information, it is not susceptible to enemy jamming. As it uses no star sights, the missile can be launched day or night in any kind of weather. Dr. C. S. Draper, AC consultant, says, "In this project, we feel that we are working at the frontiers of knowledge."

Redstone Missile Readied

Disclosures has been made that the 217th Field Artillery Missile Battalion (Redstone) has been activated as the first U. S. Army troop unit to fire the Redstone missile. Produced by the Chrysler Corporation, the Redstone is as rugged as it is deadly. It is readily transportable by air, road, rail or water. All equipment and personnel necessary to fire it can be airborne. The 60 foot weapon, the nation's biggest ballistic missile, was designed by a team of Army Ordnance scientists and engineers, including more than 100 German V-2 experts. Officials at the Army Ballistic Missile Agency, which has responsibility for the Redstone, called it a step toward the Army's future Intermediate Range Ballistic Missile (IRBM), which has been named Jupiter and will have a range of about 1500 miles.

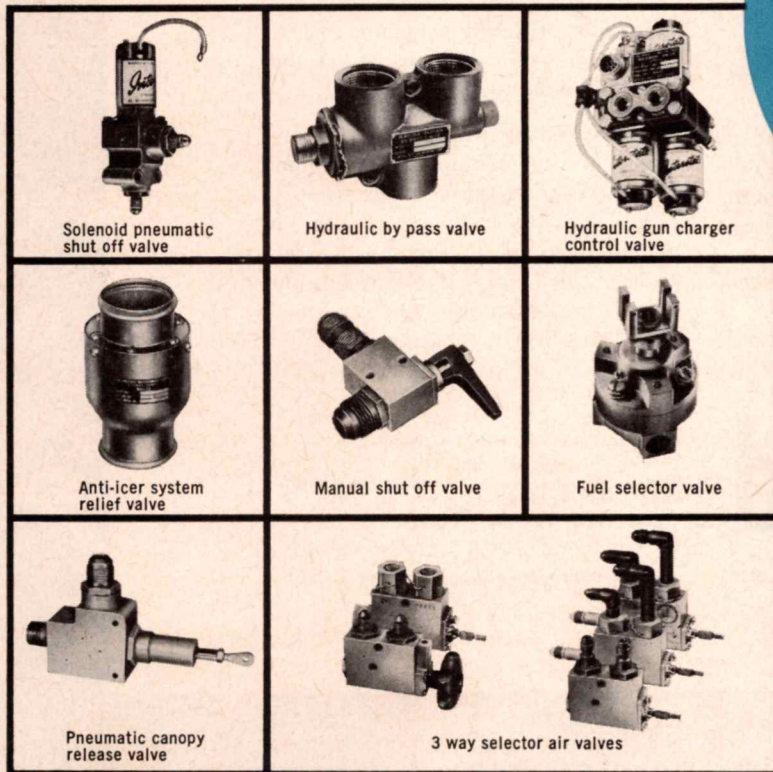
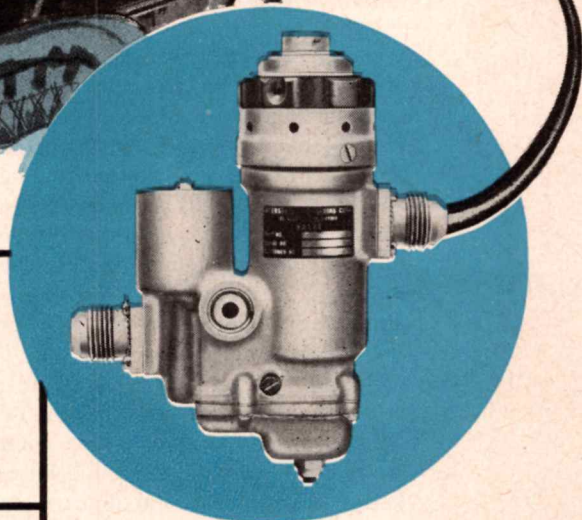
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World's Fastest Jet

The F-104 *Starfighter*, now in production for the U. S. Air Force, is the most advanced airplane of its type ever developed. *Dimensions:* height, 13 feet, 6 inches; length, 54 feet, 9 inches. *Wings:* knife-sharp, and only 7½ feet from fuselage to wingtip. *Engine:* General Electric J79, which develops more thrust per pound of engine weight than any other turbojet of comparable size. *Electronics system:* new "plug-in" type, to permit quick changes and replacements of components. *Pilot's seat:* downward firing ejection type, the first in a production jet fighter. *High, T-shaped floating tail:* twice as effective in controllability as conventional tail designs. *Armament and top speed:* both are military secrets, but the Lockheed F-104 can overtake and destroy any plane—of any size—known today.

The *Starfighter's* dart-like configuration,

perfected by extensive wind-tunnel tests, permits the F-104 to flash through the sonic barrier, routinely, without a tremor. And even at supersonic speeds the *Starfighter* has unmatched ease and decisiveness of control—because never before have so many advanced design and engineering features been so superbly combined in one aircraft.

Like all Lockheed-built planes, the *Starfighter* has inherent "design flexibility" that makes it readily adaptable to a variety of military requirements—at lowest cost to our government.

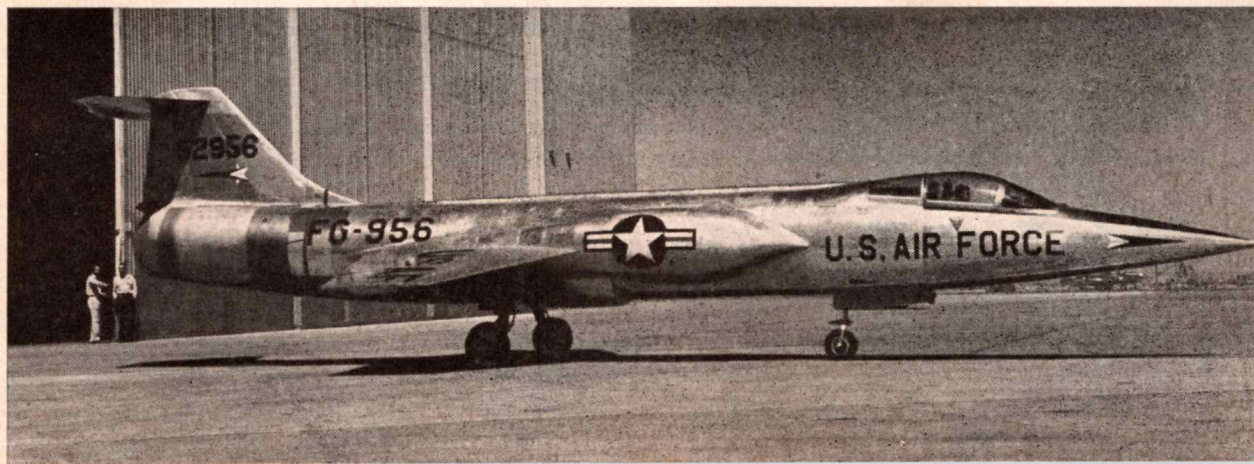
Lockheed's leadership in the design and production of military planes, of nine widely different types, stems from its policy of close cooperation with the armed services. In the F-104 *Starfighter* the U. S. Air Force has the world's fastest and deadliest jet—America's "Missile With a Man in It."

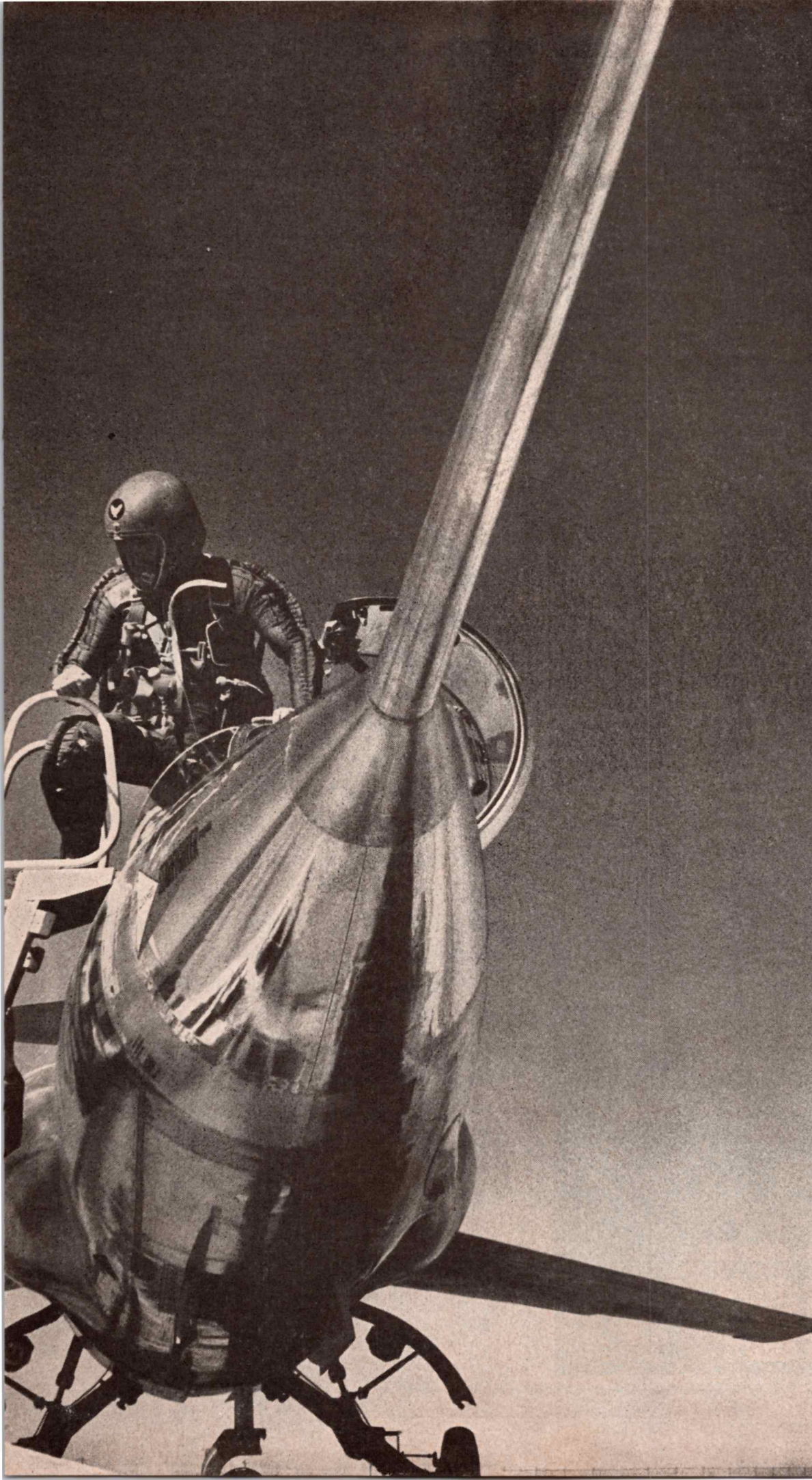
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LOOK TO LOCKHEED FOR JET LEADERSHIP, TOO





LOCKHEED'S NEWS COLUMN

Dick Tracy has lost his lead in the electronics race. His wrist radio is surpassed by a new "miniaturized" TV camera. Small enough to fit into a vest pocket, its "eye" is about the size of a cigarette. Built by Lockheed for research ONLY... (so far)...

Missile Mail is promised in the foreseeable future as a civilian development of missile technology. A Lockheed official says that the thousands of scientific and technical people now researching the whole environment of man in connection with missile development will produce civilian benefits beyond the imagination of the layman today. A letter by missile, of course, would get there faster than you could write the letter in the first place...

A Lockheed Man is working quietly in a sanctuary abroad on a nuclear engine design that will make headlines world-wide when they take the wraps off. Same man's blueprints on a nuclear contraption so startled top military authorities very early in the nation's atomic program that they locked his patent in a government vault where, for security reasons, it still remains...

Lockheed has been handed a big piece of the much-talked-about ICBM missile that will keep its Missile Systems Division scientists working nights in their new facility near Stanford University — which, incidentally, tripled in size between blueprints and ground breaking...

Beating the heat which tops 250 degrees Fahrenheit at twice the speed of sound is a matter of concern now to engineers of Lockheed's California Division who are working on methods of making airplane skin glass-smooth. Even modern, high-strength dural surfaces approach their temperature limits at these speeds...

Early America makes atomic history this month as Lockheed Georgia Division breaks ground for its new atom-powered plane facility. The 10,000-acre North Georgia site was in the same family ever since the area opened for settlement in the 1840's.



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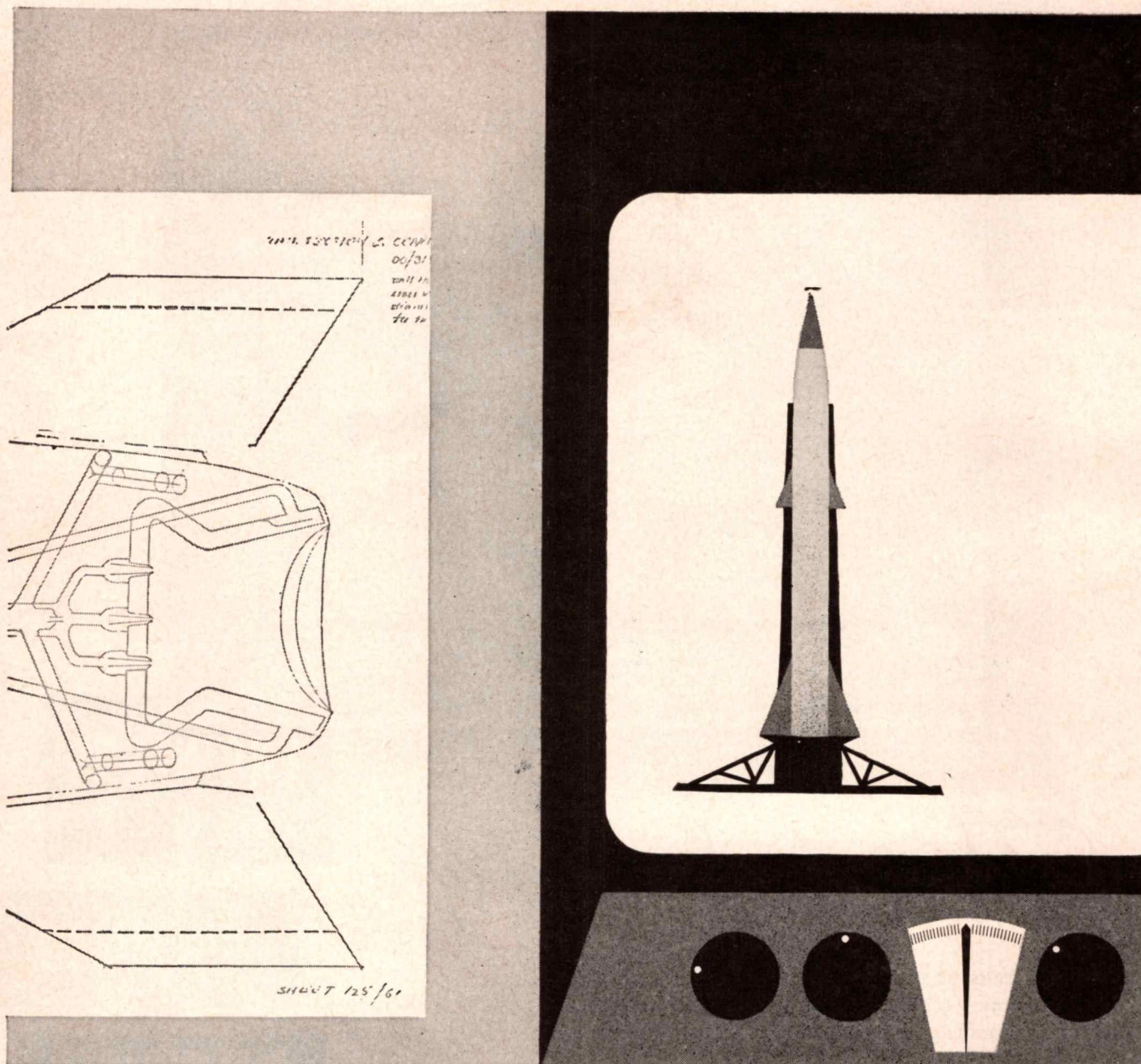
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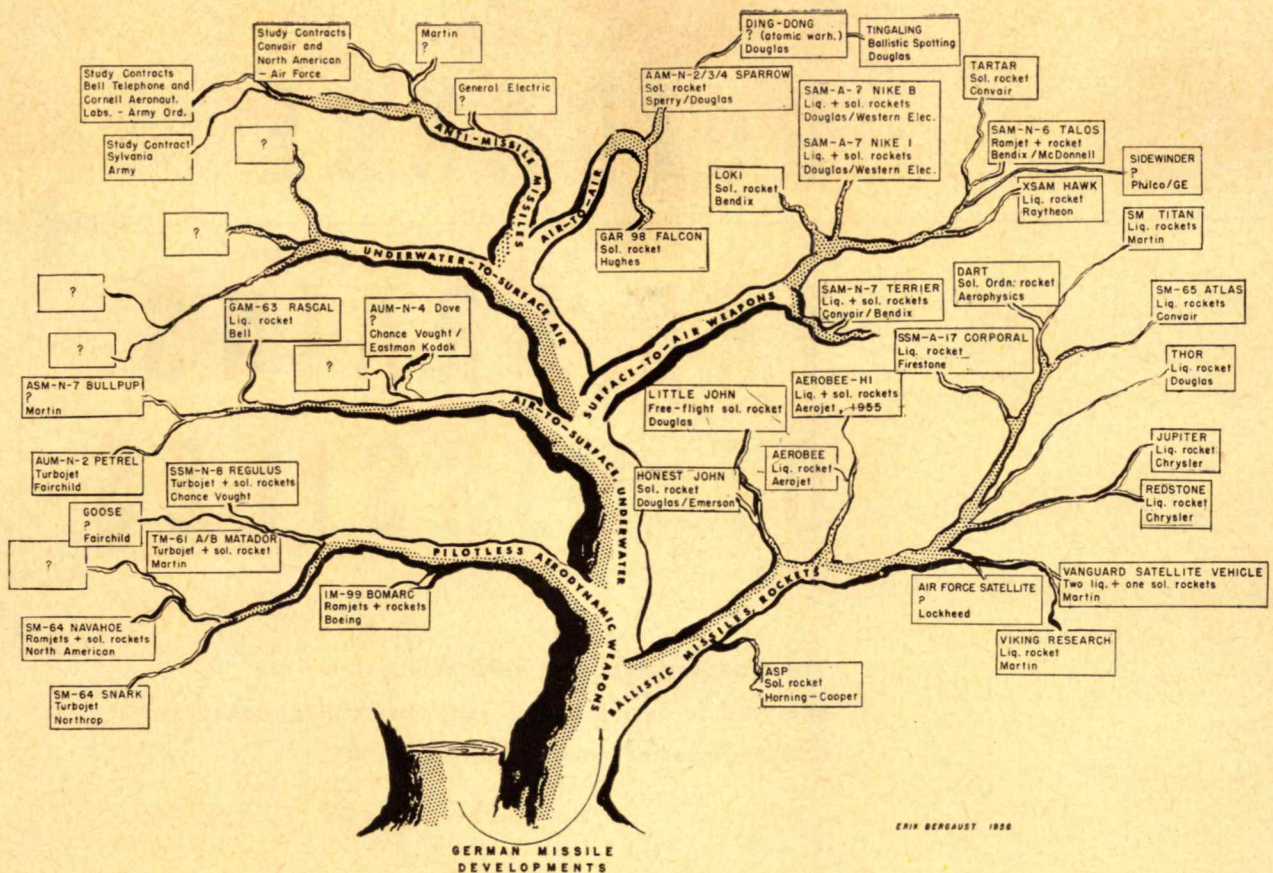


Defense Products Group

AMERICAN MACHINE & FOUNDRY COMPANY

1101 North Royal Street, Alexandria, Va.

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MISSILE DEVELOPMENTS IN THE U. S.

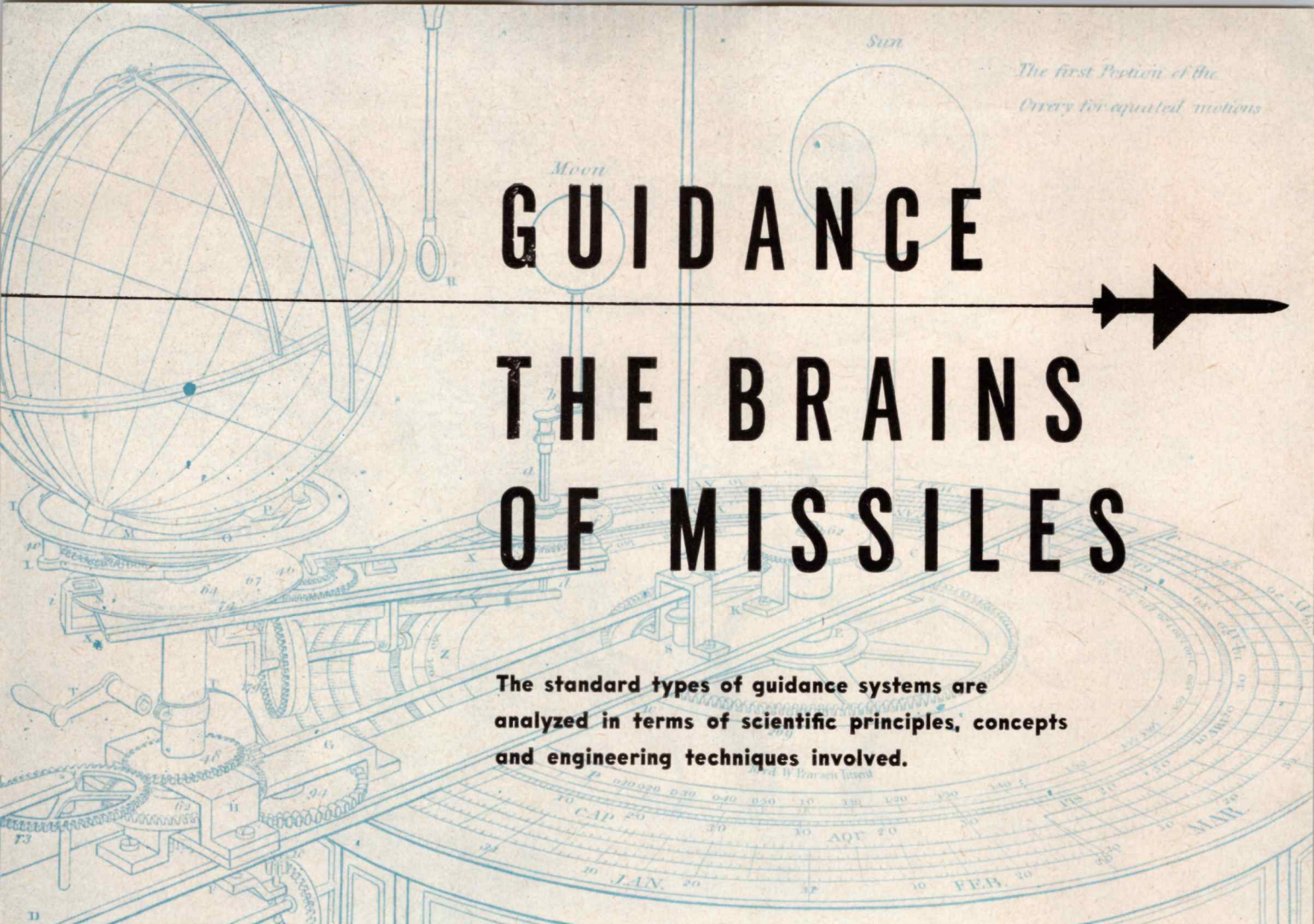
ON an over-all basis, the guided missile science of the United States is in all probability more advanced than that of any other nation. The year 1955 marked the end of the first decade of this country's guided missile development; it was during this time that most of the missiles whose names are common knowledge today were developed and produced. Their speeds extend from subsonic to hypersonic, and they have varying range capabilities, propulsion methods and guidance systems.

During the last two years rapid advances have been made; rocket and ramjet propulsion have been greatly improved. Greatest immediate progress could probably be made through improvements in reliability. While the Soviet, which resumed production of German V-2 and other missiles in 1945, has wide experience in field launching of ballistic missiles, the U. S. presumably is ahead in such

categories as surface-to-air, air-to-air and air-to-surface missiles.

The illustration above shows the U. S. guided missile families and development trends. It seems obvious that our strongest fields are the air-to-air and surface-to-air categories because missiles of the ballistic types such as the new *Jupiter*, the *Thor*, the *Atlas* and the *Titan* have not yet reached the production stage.

The left side of the family tree clearly indicates our weak sides. We know of no American underwater-to-surface/air missiles in production; and of our air-to-surface missiles only one or two are in operation. Of our long-range air-breathing missiles the SM-62 *Snark* and the SM-64 *Navaho* still have high priority, but no stockpile of these missiles is available in case of emergency. In view of the Soviet submarine threat, it seems obvious that we must now concentrate on air-to-surface, underwater-to-surface and anti-missile missiles.



GUIDANCE THE BRAINS OF MISSILES

The standard types of guidance systems are analyzed in terms of scientific principles, concepts and engineering techniques involved.

DANIEL T. SIGLEY

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General Engineering Laboratories
American Machine & Foundry

N. I. KORMAN

Assistant Chief Engineer
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Radio Corporation of America

GUY WORSLEY Supervisor,
Guidance Intelligence Group
Applied Physics Laboratory
The Johns Hopkins University

THE AUTOMATIC GUIDANCE system of the present-day guided missile is an intelligent machine. The intelligence system, with its associated launching site equipment, is a complex of integrated electrical and electro-mechanical equipment designed to give the missile the ability to make its own decisions automatically. What is the nature of the techniques used in guiding missiles? To help answer the question, this article attempts to present explanations of some of the standard types of guidance systems. Details on the designs, present status, and tactical use have been intentionally avoided to conform with the present security regulations imposed by the government on this field of activity.

● ● Guidance Principles

Electronic equipment and components may account for up to 85 percent of all guidance equipment. The remainder consists of mechanical instruments such as gyroscopes, hydraulic servomechanisms and optical equipment. The scope of missile guidance is broad

and as such draws from the majority of scientific principles. Some of the concepts are unique in the field of missile guidance. Examples are given in Table 1.

● ● Special Techniques Used in Guidance

The spectacular development of guided missiles has been stimulated and made possible by the extension of many old techniques and the invention of many new electronic and other guidance techniques. Challenged by the need for an order-of-magnitude improvement in size, weight, reliability, accuracy of performance, and survival under stringent environmental conditions, new concepts of component design and means for their employment have evolved. Some of the unusual techniques that have been developed for missile guidance are listed in Table 2.

All the functions that must be performed within a guided missile are related. Thus the propulsion plant, the aerodynamic and dynamic response, the fuze, warhead and missile power supplies all affect the design

and operation of the guidance system, and conversely. This interrelationship requires that the design of a guided missile be considered as a complex system, each part or subcomponent of which is chosen to match other components in the system. The guidance system plays the major role in the system design. The schematic diagram of the guidance system shown in Figure 1 is considerably simplified but illustrates a typical sequence of operations which are performed automatically as the missile proceeds along its trajectory toward the target.

● ● Role of the Control System

One of the main components in a guided missile is the control system and its associated computers. In a missile flying within the atmosphere, the control system converts the steering intelligence signals into wing, tail surface, aileron or rudder motions which will cause the missile airframe to generate lift and accelerate itself in the direction specified by the intelligence system. Input steering signals to the control system regulate the power flowing into the pitch, yaw and roll actuators which, in turn, move the aerodynamic steering surfaces.

Missile steering in the atmosphere is performed by independently controlling the moments due to the lifting forces generated about each of the three axes of pitch, yaw and roll. This method of control is different from that used in steering conventional manned aircrafts in which the airplane is banked-to-turn. When the missile is being flown outside the atmosphere, the situation is similar except that these sidewise acceleration forces must be generated by reactive forces from rocket gases or the equivalent.

The control system consists of three channels. The first of these corresponds to the roll stabilization system loop shown in Figure 1. This roll stabilization system derives intelligence about its attitude from a gyroscope. Signals are developed and applied to the roll control surface actuators to produce counter-rotating torques which rotate the missile to its correct attitude.

The other two channels in the control system represent the arteries of control for pitch (up-down) and yaw (right-left) steering operations. Intelligence signals picked up by a guidance intelligence receiver are converted to control signals in the computer. This computer also modifies these signals to compensate for changes in missile speed, air density, time-to-go, sensitivity of the system, maneuverability limits and the like, as the missile proceeds along its trajectory.

The control system of a missile must use the intelligence signals to steer faithfully the missile on its required trajectory. As such, the control system and computer contribute significantly to the successful performance of the guidance operation. Two of the most critical characteristics of a control system are the output power of the system and its speed of response. Power requirements for the control system are set by the torques required to move the control surfaces and the necessary speed for accomplishing these motions. Servo systems for missile application have been designed for horsepower ratings ranging

TABLE 1

SCIENTIFIC CONCEPTS USED IN MISSILE GUIDANCE

DEFINITION OF TRAJECTORIES

- 1) **Pursuit Course Homing**—The velocity vector of the missile is controlled so that it always points to the target.
- 2) **Interception Navigation**—The direction of the missile velocity vector is controlled so that the rate of rotation of the line-of-sight in inertial space vanishes.
- 3) **Proportional Navigation**—The missile velocity vector is forced to rotate in inertial space at a rate which is n times the rate of rotation of the line-of-sight to the target. The number n is defined as the navigation constant.
- 4) **Ballistic (or Satellite)**—The missile, after attaining its flight velocity, is acted on only by the force of gravity.
- 5) **Circular Satellite Orbit**—The speed of the satellite is such that the resultant force required to keep the satellite in a circular path is equal to the earth's gravitational force if secondary gravitational forces from other stellar bodies are neglected.
- 6) **Magnetic Field Path**—Loci of constant magnetic intensity in the earth's magnetic field define navigation lanes around the earth's surface.
- 7) **Radar Beam Rider**—The missile is constrained to fly along the axis of a radar beam. The same beam may be tracking the target at the same time.
- 8) **Inertial Instruction Controlled**—The missile is constrained to follow a path established by programmed settings of inertial instruments.

CONTROL PRINCIPLES

- 9) **Automatic Regulation**—Any deviation from the regulated position results in automatic recovery to the regulated position.
- 10) **Servomechanism Control**—Small signals control large torques or forces through torque or power amplifiers called servomechanisms.
- 11) **Acceleration Feedback**—Steering signals representing desired accelerations are compared (automatically) with measured missile accelerations, and any difference is used to modify the missile flight path so that the desired and actual accelerations become equal.
- 12) **Open-Loop Control**—A signal is used to produce or govern a response, but the response is not measured or used to influence the input signal.
- 13) **Closed-Loop Control**—A signal is used to produce a response, and the response is then measured and compared with the signal that produced it to insure that the response is correct.

TABLE 2

UNUSUAL TECHNIQUES USED IN MISSILE GUIDANCE

- 1) **Automatic Tracking of Moving Targets**
 - a) Obtaining position data on several targets simultaneously by surveillance radars.
 - b) Monopulse or simultaneous lobe comparison radar tracking to obtain increased accuracy.
 - c) Improved performance of precise tracking radar mounts.
- 2) **Homing and Fuzing Devices**
 - a) Radar homing heads which automatically track the target from reflected echoes or target emanations.
 - b) Combining of homing heads and control systems to steer a missile on a pursuit, collision, or proportional navigational course.
 - c) Steering a missile into an interception with the target by constraining it to follow along the electrical axis of the radar beam which is tracking the target.
- 3) **Inertial Guidance Developments**
 - a) Gyro-stabilized inertial references of greatly improved accuracy.
 - b) Accelerometers and integrating accelerometers of greatly improved accuracy.
 - c) Missile-borne automatic star tracking telescopes.
- 4) **Electronic Position Measuring Developments**
 - a) Magnetometers to measure the intensity of the earth's magnetic field.
 - b) A number of phase-measurement base line guidance systems of improved accuracy.
 - c) Lightweight missile-borne r-f antennas and receivers.
 - d) Digital and analog computers capable of solving the complex problems associated with fire control prediction and coordinate conversion for use in guidance equipment on the ground.

from a fraction of a horsepower up to 50 horsepower. Both electric and hydraulic systems are in current use. High-speed control systems are required to obtain the full capability of the aerodynamic maneuverability of high-speed missiles. As a general rule, the natural frequency response of the control system should be of the order of 10 to 20 times that of the airframe.

● ● Simulation

Accurate or precise measurements of the performance of all parts of a guided missile, including propulsion, aerodynamics, control system operation, power supplies, computers, fuze and warhead operation, are difficult. Flying the missile against a target is one way to measure this overall performance, but the process is usually expensive in terms of money expended and of elapsed time required to fabricate test missiles. Testing by flying is supported and supplemented by the technique of flight simulation, in which the missile or component under test is not expended by the test. Under simulated flight, missile components and computational elements are set up in the laboratory to represent the complex missile. Some parts of the missile system, especially those under investigation at the moment, may actually be employed in the experimental set-up. The component may be a missile-borne radar receiver, a computer, power supply, control loop, transfer valve, gyroscope or telemetering link. In the simulated operation, elusive aerodynamic and dynamic responses of the missile can be computed on specialized electronic digital or analog computers; linear accelerations and velocities may be represented by rotational accelerations and velocities; and roll stabilization equipment may be mounted on rotating tables in which the mass of the

table, the restoring moments and the damping forces are reproduced to correspond to those associated with the actual missile.

In a simulated flight, the guidance system, in conjunction with the simulated target, forms a closed-loop system in which the motion of the target as an input causes changes in the missile trajectory. The effects of other phases of missile operation on the guidance loop may be injected at various points in the loop. Thus a change in missile speed, in air density, in voltage from the regulated power supply, in the sensitivity of the control system, and so on, can be programmed into the simulator study. Components can also be operated in a wide variety of environmental conditions such as at reduced air pressure, under high-static or dynamic accelerations, at high temperatures, and other similar conditions.

The objectives in a simulator study may vary. It may be desired to show that a particular guidance system is effective in a tactical situation; to show that certain changes in the parameters of the system will increase the guidance accuracy against a particular type of target; or to show that the speed of response of the control system needs to be altered to make it compatible with the maneuverability of the missile. The output from the simulator study is usually a series of curves, some of which may show the actual trajectory flown by the missile, the turning accelerations generated by the missile in its flight path, the deflections of the ailerons to produce these accelerations, or the roll attitude of the missile. These curves can be analyzed for malperformance or for possible improvements in design. Suggested improvements can be incorporated and the test can be rerun on the simulator. A comparison of the two sets of curves will then show the relative performance in the overall system result-

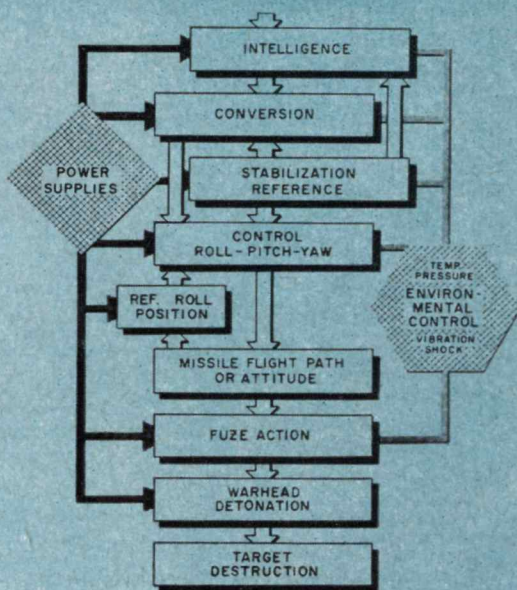


Figure 1—Typical missile borne guidance system block diagram.

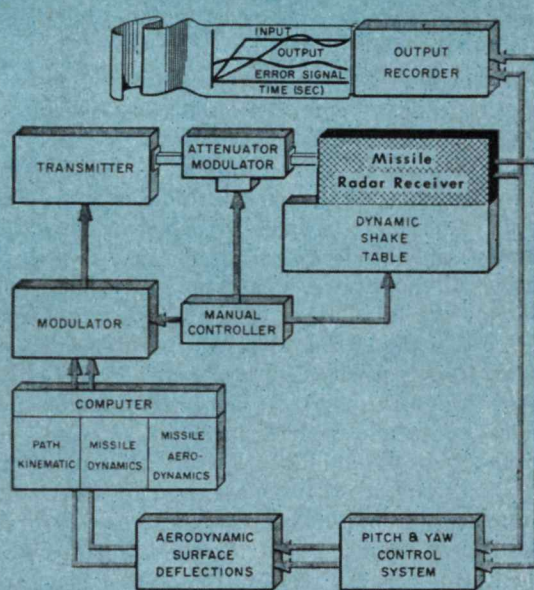


Figure 2—Typical laboratory simulation test of missile radar receiver block diagram.

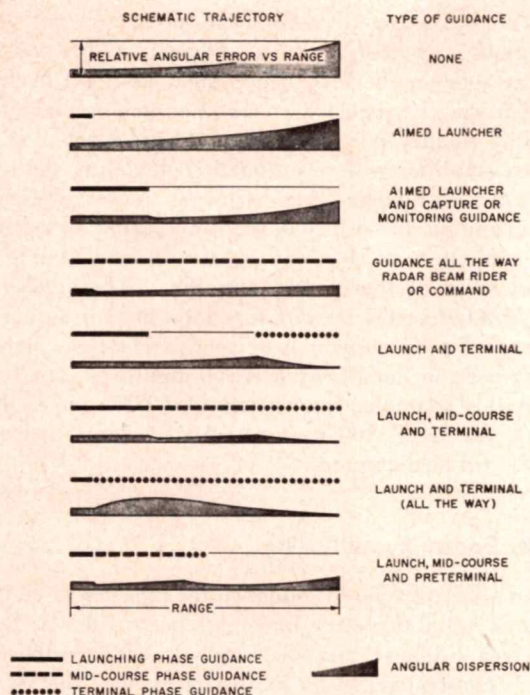


Figure 3—Guidance systems and accuracies.

ing from the change in one or more of its component parts.

Figure 2 shows a block diagram of a typical simulator test arrangement for studying the performance of a missile-borne radar receiver. The figure also illustrates the type of data that is obtained from the recorders.

• • Errors in Guidance Systems

The guidance equipment in a missile must furnish the information necessary to direct the missile to the target. The physical size of the target, the specified point on the target at which the warhead must detonate, the warhead lethality, and the vulnerability of the target all influence the accuracy with which the missile must be guided. Thus, for the destruction of a bomber aircraft, the guidance accuracy may be specified as a direct hit or a near miss of 10 feet, 50 feet,

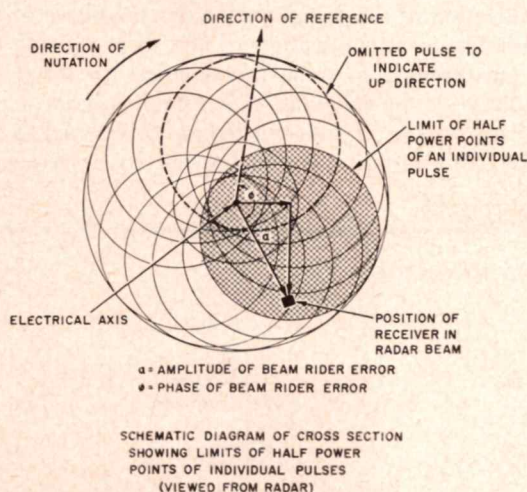


Figure 4—Lobed pulsed radar beam.

200 feet or any intermediate or greater value. This permissible near miss will depend on the vulnerability of the aircraft to the missile warhead.

An automatic guidance system will deliver missiles to the point of aim with a certain dispersion pattern somewhat like that produced when shooting at a target with a rifle. The probability of kill on the target, a measure of the ultimate effectiveness of the missile, depends upon the magnitude of the guidance miss distance at the target. Miss distances expected are a function of equipment design and guidance system operation.

Figure 3 is a diagrammatic representation of the way in which the miss distance to be expected from various types of guidance systems changes at various ranges along the trajectory. The curves plotted in this figure are intended to represent, qualitatively, the magnitude of the angular error measured at the launching site to be expected for the various types, or combination of types, of guidance equipment. The ordinate is the angular miss distance from the interception point. The abscissa represents the range to the target which is considered to be each of the successive points in the trajectory. For instance, the curves show

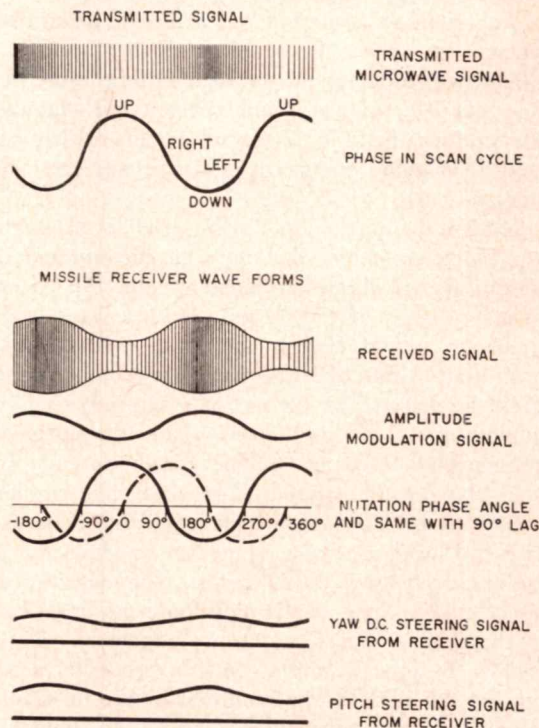


Figure 5—Tracking and guiding radar transmissions.

that the miss distance increases with R^n for range R , where the exponent n is greater than unity when the missile is guided only during the initial or launch phase; that radar beam rider guidance errors increase approximately linearly with range R ; homing errors, neglecting the transition phase, decrease with range (down to the minimum operating range), and mid-course systems may have errors which may or may not be range dependent.

At the point of initiation of automatic guidance, a transient response will occur unless, by chance, the

missile has precisely the initial conditions for steady-state operation. The qualitative error curves show the effect of these transients, for instance, in the case of activation of homing. The angular errors for all homing guidance show a decrease as the range from the launching point increases because the error excursions or deviations are largest due to the transient behavior of the system at the time of activation and because the angular error decreases as the range to the target decreases.

● ● Frequencies Used in Missile Guidance

Two types of signal transmission are used in missile guidance. Guidance signals between ground stations and a flying missile are transmitted over a radio link, while those within the missile or ground station are transmitted by conventional wire, wave guide or printed conductors. The frequencies used in the radio transmission are listed and classified in Table 3.

Guidance information may be carried on radio waves having any frequency listed in Table 3. The guidance signals themselves may be represented as an amplitude or frequency modulation on a continuous or pulsed carrier signal, as a phase difference between two carriers or a carrier and a locally generated frequency, or as a time spacing of short pulses. The guidance equipment on board a missile must be capable of detecting and analyzing these signals and interpreting them in terms of signals which can be used to actuate wings or steering surfaces on the missile.

The following example will serve to illustrate the range of frequencies that may be encountered in the operation of a single guidance system. An r-f carrier on a frequency of 10,000 mc/s with a wave length of 3 cm may be carrying an amplitude modulated signal at a nutation rate of 100 cycles per second. The signal might be detected by the aid of a heterodyning system employing a local oscillator on the missile having a frequency of 9970 mc/s. The missile antenna system would have to be capable of receiving the carrier frequency of 10,000 mc/s which would be made to beat with the local oscillator signal to produce the intermediate frequency of 30 mc/s. The detector would detect the envelope of the amplitude modulated signal at the 100 cycles/s nutation frequency. The 100 cycle/s frequency might be converted to a slowly varying d-c signal to be modified by the missile-borne computer and, subsequently, used to control the motion of the wings or ailerons.

The servo system itself may operate on d-c or on alternating current having a frequency of 400 cycles/s, or at some higher frequency such as 2400 cycles/s. The higher frequency is usually chosen to permit the use of smaller condensers and transformers. If the servo amplifier, whose output is controlling the spool of a transfer valve of a hydraulic power system, is operating on 400 cycles/s, the d-c steering signal from the computer could be fed in as a bias voltage at the input stage of the control amplifier. Alternately, the d-c voltage could be converted to an a-c signal by means of a vacuum tube or mechanical-type inverter to be used in the 400-cycle servo amplifier.

In this example, frequencies of 10,000 mc/s, 9970 mc/s, 30 mc/s, 100 cycles/s, 400 cycles/s and zero (d-c) are encountered.

● ● Radar Beam Riding

An effective type of guidance for missiles to be used against aerial targets is known as beam rider or beam follower guidance. In this form of guidance the missile is constrained to fly in such a manner that it will remain on or very close to the axis of a radio or radar beam. This guidance system uses guidance components at the launching site and on the missile. The expendable equipment carried on the missile is comparatively simple.

The guidance beam is generally narrow, one-half to three degrees at its half-power point, and so is most conveniently formed by a highly directive antenna such as a parabolic reflector transmitting centimeter wave length signals. The guidance beam nutates or rotates about the desired guidance axis with a total excursion of about one beam width (measured at the half-power points). The rate of motion about the guidance axis is of the order of 10 to 100 rotations per second. If the missile is on the guidance axis, the net effect noted at the missile intelligence receiver is that the signal received on board the missile will be constant and not modulated at the rotation frequency. If, on the other hand, the missile is displaced from the guidance axis, modulation at the rotation frequency will be noted. The amount of modulation is an indication of the distance off axis; the phase of the modulation is an indication of the direction off the axis measured from some preset reference direction. The phase of the modulation is established on a roll stabilized missile by transmitting another signal to the missile. For instance, it can be sent by a frequency

TABLE 3—RADIO FREQUENCIES AND WAVE LENGTHS

Classification	Frequency Range	Wave-length Range
Very low frequency	10-30 kc/s	30,000-10,000 meters
Low frequency	30-300 kc/s	10,000-1000 meters
Medium frequency	300-3000 kc/s	1000-100 meters
High frequency	3-30 mc/s	100-10 meters
Very high frequency	30-300 mc/c	10-1 meter
Ultra high frequency	300-3000 mc/s	100-10 centimeters
Super high frequency	3000-30,000 mc/s	10-1 centimeters

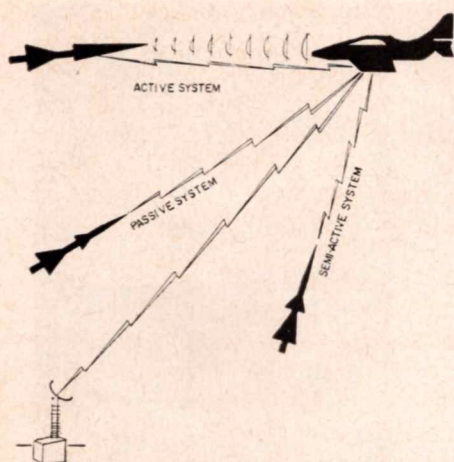


Figure 6—Types of homing systems.

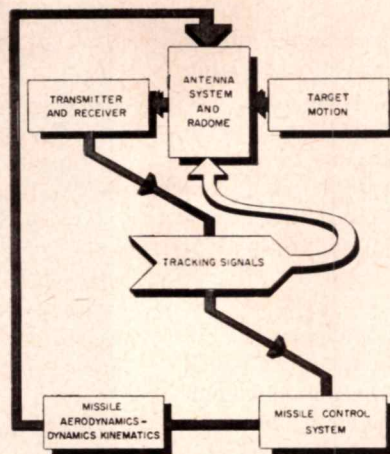


Figure 7—Typical homing system.

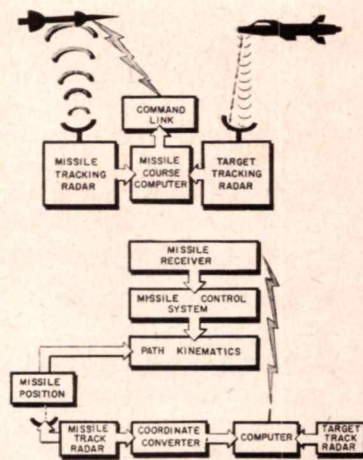


Figure 8—Command guidance block diagrams.

FORMULAS FOR RADAR HOMING

Gain of a reflector; $G_0 = \frac{4\pi A_f}{\lambda^2}$, $0.5 < f < 1.0$

Effective receiving cross-section; $A_r = \frac{G\lambda^2}{4\pi}$

Reflecting area; $\frac{\sigma}{4\pi R^2}$

Signal strength received; $P_R = \frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$

Maximum range; $R_{max} = \sqrt{\frac{4 P_T \sigma G^2 \lambda^2}{(4\pi)^3 P_{RMIN}}}$

One-way transmission; $S_b = \frac{P_r G_r G_b \lambda^2}{16\pi^2 R^2}$

Johnson Noise; $N = KTB$

Noise figure of receiver; $F = \frac{S}{S_0} \frac{N_0}{KTB}$

modulation pattern on the guidance pulses of the pulsed radar.

The rotating pulsed guidance beam then contains the basic intelligence to be decoded by a missile to determine its polar coordinate position relative to the axis. The diagram of Figure 4 shows the geometrical arrangement of the pulses about the electrical axis. The wave forms which a beam rider receiver unscrambles from the beam are shown in Figure 5.

The beam riding missile can be guided over a variety of trajectories. In the simplest of these, the trajectory lies along the line-of-sight from the launching point to the target. In this case, the guidance beam coincides with the radar beam used for tracking the target, and considerable economies of equipment become possible. A somewhat more sophisticated trajectory is one in which the missile is caused to climb rapidly to its most efficient cruising altitude and then is compelled either to climb to or to dive on the target

near the end of its flight. This type of trajectory can be accomplished by controlling the guidance radar beam by a ground computer which programs the direction of pointing of the beam. A second beam tracks the target to supply the beam-controlling computer data on the target location.

• • General Types of Homing

For an anti-aircraft missile being controlled from the launching site, the guidance inaccuracy measured in feet from the desired trajectory tends to increase as the range increases. Under this condition the missile intercepts the target at the time the error is greatest. A general type of guidance system—called homing—eliminates this deficiency by transferring the effective guidance point to the target itself. For radar homing, the target is illuminated either from the missile (active homing) or from the launching point (semi-active homing) by electromagnetic radiation. The echo reflected from the target is then received by the missile through an antenna system which is capable of determining either the direction to the target with respect to the missile heading or the rate of change of this direction or both. Missile homing systems may also use the radiant heat generated by the target or electromagnetic radiation transmitted by the target as homing intelligence signals (passive homing). Active, semi-active and passive homing systems are illustrated schematically in Figure 6. A block diagram showing the operation of a typical homing system is given in Figure 7.

In some missiles the antenna system is caused to point continuously at the target by virtue of its servo-actuated direction finding capabilities in much the same fashion as a ground located tracking radar. The missile control system can then be designed to fly the missile so that it will align itself with the antenna and point directly at the target. This results in the pursuit type of course.

A more sophisticated approach is to measure the rate of rotation of the antenna with respect to the missile, measure the rate of rotation of the missile in inertial space by means of a gyroscope and thereby determine by the combination of these two measure-

ments the rate of rotation of the line-of-sight to the target in inertial space. Now by controlling the missile to fly a course that will reduce this last rate of rotation to zero, it will tend to close on a constant velocity approaching the target along a straight line collision course. This type of navigation represents an application of surface navigation principles to the navigation of an airborne missile. A proportional navigation course can also be obtained with this rate information.

● ● Command Guidance

The minimum amount of guidance equipment required in a missile is obtained in the system in which the majority of the intelligence gathering and computation is done at the surface or launcher location. A system that uses this principle is the command guidance system. Its operation is based on tracking an airborne target with one set of radar equipment and tracking the missile with another independent set of equipment. These tracking data, consisting of target and missile coordinates (and velocities), are then processed by a ground-based computer which determines the flight path that the missile must fly to intercept the target.

Steering orders are also computed on the ground and transmitted to the missile receiver and control

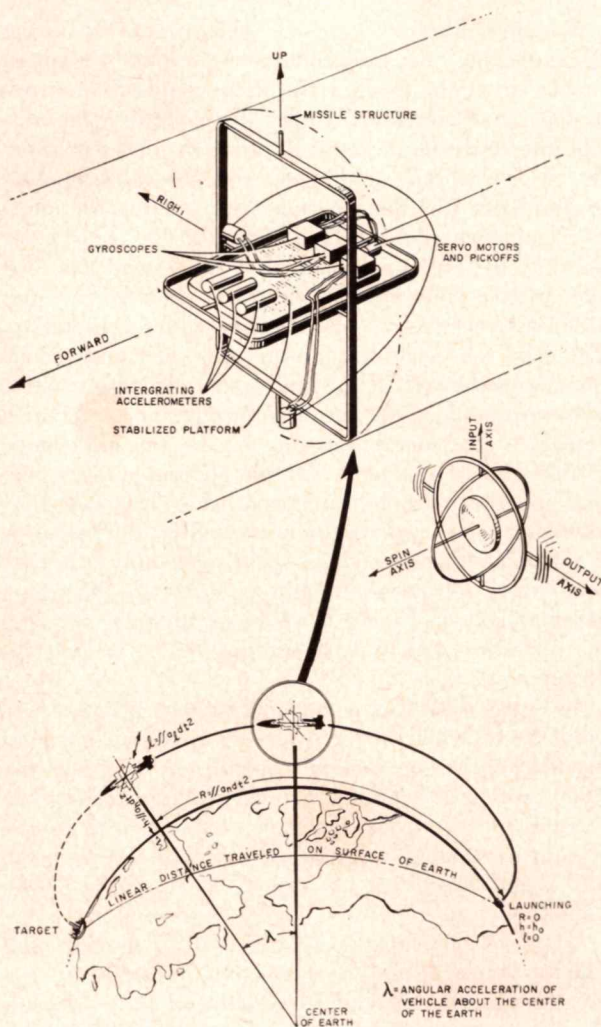


Figure 9—Inertial space reference systems.

FORMULAS FOR ELLIPTIC AND CIRCULAR ORBITS

Ellipse of ascent

$$F = -\frac{\gamma M m}{r^2}, \text{ law of attraction}$$

$$r^2 \dot{\theta} = C, \text{ a constant}$$

$$1/r = \frac{\gamma M}{C^2} + A \cos \theta$$

Typical Case

$$h_p = 65 \text{ mi}, V_p = 5.13 \text{ mi/sec}$$

$$\gamma M = 9.56 \times 10^4 \text{ mi}^4/\text{sec}^4$$

$$C = 2.065 \times 10^4 \text{ mi}^2/\text{sec}, A = 2.5 \times 10^{-5}/\text{mi}$$

$$r^2 \theta = 2.065$$

$$r = \frac{4480}{1 + 0.111 \cos \theta}$$

$$h_0 = 1075 \text{ mi}$$

$$V_0 = 4.11 \text{ mi/sec}$$

$$V_{0h} = 1075 = 4.39 \text{ mi/sec}$$

$$V_s - V_{0s} = \Delta (1/5) = 0.28 \text{ mi/sec}$$

Circular Orbit

$$V_s = R_0 \sqrt{\frac{g_0}{R_0 + h}}, g = g_0 \left(\frac{R_0}{R_0 + h} \right)^2, V_s = \sqrt{2} V_0$$

$$T = \frac{2\pi}{\omega} = \text{the period}$$

$$\frac{R_0 \sqrt{g_0} T}{2\pi (R_0 + h)^{3/2}} = 1$$

$$E_p = R_0 g_0 \cdot \left(\frac{h}{R_0 + h} \right), E_K = \frac{1}{2} \frac{R_0^2 g_0}{R_0 + h}, E_T = \left(\frac{R_0 + 2h}{R_0 + h} \right) \frac{R_0 g_0}{2}$$

system either by a modulation signal on the tracking radar beam or by an auxiliary radio communication link. Actual signals transmitted may be the pitch and yaw control surface deflections which can be applied directly to the control surface actuators.

The design of the ground computer may be quite elaborate and take into account such factors as the optimum flight path to maximize range, minimum time of flight and maximum probability of interception, as well as varying aerodynamic factors caused by altitude and speed changes. Since the computer is not carried by the missile and expended during the flight, there is no necessity for compromising it for simplicity, lightness and adaptability to the rigorous missile environment.

The basic concept used in the design of a command guidance system is shown by the block diagrams of Figure 8. The first diagram indicates the general arrangement for the guidance equipment. The second block diagram gives a slightly more detailed breakdown of the equipment aboard the missile.

● ● Inertial Guidance

Guidance systems for surface-to-surface missiles for the destruction of ground targets at ranges of 50 miles to 5000 miles must be designed around different principles from those used in missiles to be launched against aircraft. The distances are great enough so that the curvature and rotation of the earth must be taken into account.

Guidance can be achieved by navigational methods. One procedure would be to navigate completely by

means of information obtained from, or with respect to, the earth. Phase-measurement base line radio navigation systems and terrain recognition systems are examples of this type guidance. No direct contact with the target is necessary during the guidance phase of the flight. However, these systems are subject to the inherent errors in radio transmission and enemy countermeasures. A second method would be to navigate in inertial space through the conversion of all positions, directions and distances into inertial space measurements. Instruments available for inertial navigation include gyroscopes, pendulums and mass-on-a-spring accelerometers.

The heart of such an inertial navigation system is a space stabilized platform which carries three doubly-integrating accelerometers as distance measuring devices. See Figure 9. The reference system can maintain its orientation in inertial space through the action of a servo-controlled gimbal system deriving intelligence from three gyroscopes with output axes mutually perpendicular and pointing along the three coordinate axes. The integrating accelerometers measure the distances traversed in the direction of the three sensitive axes; two accelerometers can be used to indicate altitude and transverse deviations from the plane of the great-circle trajectory, and the third can be arranged to measure forward progress along the trajectory.

It is easily seen that the alignment of the platform and its associated accelerometers is critical. The accuracy of the distance or range measurement depends upon the precision with which the axis of the range accelerometer is maintained in the instantaneous horizontal plane as the missile proceeds around the earth. The direction of the gravitational vertical, or an equivalent, is required to set the stabilized table in a horizontal plane.

Although an inertial guidance system is rather simple in concept, its development and perfection is beset with many practical engineering problems. The automatic guidance equipment required to instrument a 5000 mile missile prescribed to have a CPE (radius of 50 percent circle) dispersion at the target area of one mile presses engineering technology on two fronts. First, there is the geodetic problem associated with the accurate determination of the launching and target locations from which the direction and length of the great-circle path are obtained. To have a reasonable probability of obtaining the prescribed one mile CPE accuracy on the target, each of the two locations must be known to a precision considerably better than one mile CPE. Secondly, the precision of the measurement gyroscopes and accelerometers is hypercritical. For example, an error of 0.0001 ft/sec^2 (three parts per million in the acceleration of gravity) in setting the zero on the accelerometer which measures the distance traversed along the trajectory would accumulate a range error of 3870 feet in a flight of 8800 seconds. This is the duration of a 5000 mile flight by a missile whose average velocity is 3000 ft/sec (approximately Mach 3). For a Mach 10 mis-

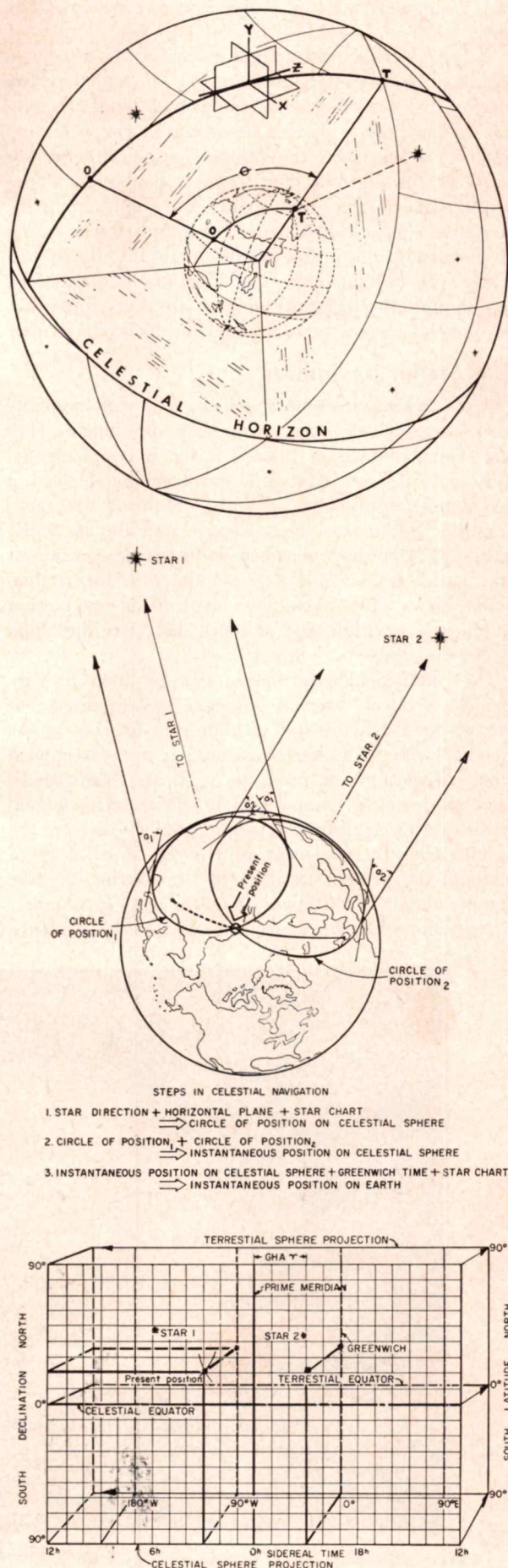


Figure 10—Celestial navigation principles.

sile, the error from this source is of the order of 380 feet.

A basic dynamic 84-minute oscillation is associated with a missile being automatically controlled by an inertial instrument system. The gravitational acceleration of the earth produces transients in the speed and flight directions of a free-falling missile with periods equal to the periodic motion of a pendulum whose length is the radius of the earth. The amplitude of the oscillations is a function of the external forces acting on the missile and initial conditions set into the system at the time of launching. The effect of the oscillations can be minimized by providing an auxiliary input into the inertial system for damping the cyclic variations.

● ● Stellar Navigation

Star-tracking telescopes which will automatically track the brighter stars have been developed. If a platform stabilized in inertial space is supplemented with one of these automatic star tracking devices, a stellar-inertial guidance system is obtained. The combination of the tracking telescope and the inertially stabilized horizontal platform will provide continuous or intermittent altitude data on the brighter navigational stars. The principles involved in navigation from stellar altitude and azimuth data are illustrated in the diagrams of Figure 10.

This additional information can be used to supplement a purely inertial guidance system in one of two ways. First, the star altitude and bearing angle, together with star chart information and Greenwich time, will permit the resetting of the inertially stabilized platform to compensate for drift. The second application uses altitude information derived from the simultaneous measurement of two or more stars to compute the present position of the moving missile. The precomputed altitude data on the stars for the predicted flight schedule can be inserted into the guidance

mechanism as a program in the elevation of the telescopes to be maintained along the trajectory. If the actual altitude of the observed stars is different from the programmed schedule, the missile engine can be throttled to make up for lost time or to delay the missile. When used in this manner, an auxiliary power-plant would be required throughout the free-flight of the missile.

● ● Satellite Missile Guidance

Placing a satellite missile on a circular orbit represents a guidance problem which is an extension of the inertial or inertial-celestial type previously discussed. In fact, a long-range bombardment missile would become a satellite if its speed at the end of its sustained propulsion period were sufficiently great. Under the gravitational law of attraction, if the drag due to the atmosphere is neglected, the free-flight trajectory is an ellipse with the center of the earth as a focus. If the launching speed is not great enough, the elliptic orbit intersects the earth and the missile will return to the earth as illustrated by a bombardment missile. If the speed is increased, the elliptic orbit will pass completely around the earth. A satellite in such an orbit will obey Kepler's laws and, hence, will speed up and slow down as it traverses the elliptic orbit. If the velocity of the satellite is chosen so that the centrifugal acceleration of the satellite, when flying parallel to the surface of the earth directly beneath it, is precisely equal to the acceleration of gravity at the flight altitude, the orbit will be circular. If the satellite has a speed which is greater than $\sqrt{2}$ times the speed of a satellite in a circular orbit, the trajectory will become hyperbolic and the satellite will escape from the earth's gravitational field.

The diagram of Figure 11 shows a satellite missile being projected by a three-stage booster to the perigee point in an elliptic orbit. At the end of boost, the

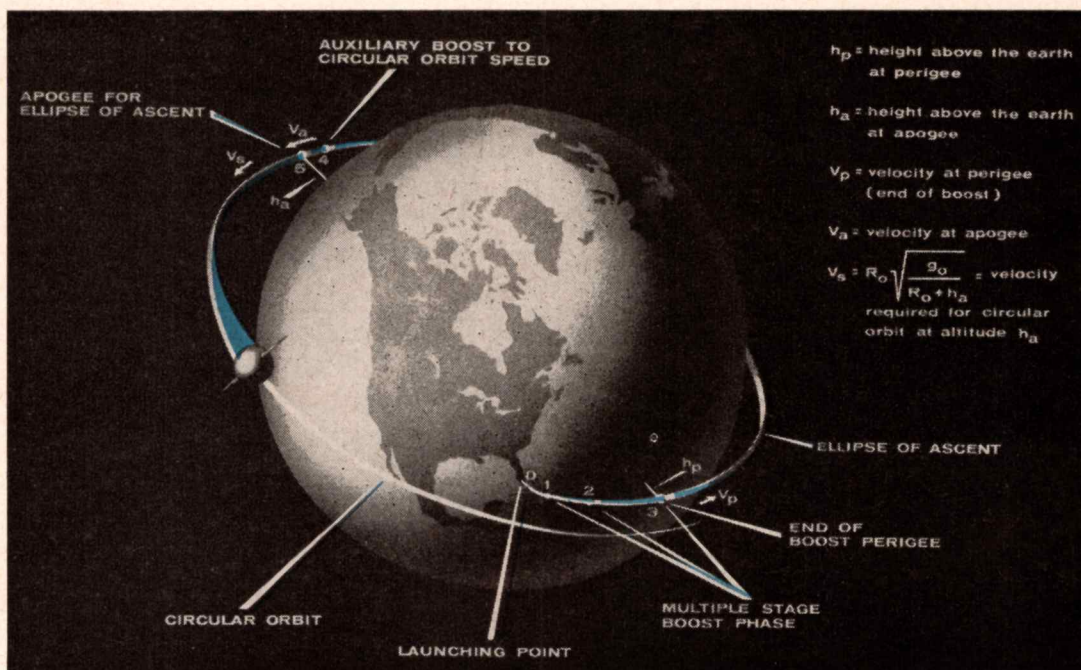


Figure 11—Earth Satellite.

speed V_p is greater than that required for a circular orbit at that altitude h_p . The satellite then proceeds to move along its elliptic orbit, during which motion it climbs away from the earth to an apogee altitude h_a . At the latter altitude the speed has decreased to V_a which is less than that required for a circular orbit at the altitude h_a . If, at the time that satellite reaches the apogee point, the speed is increased by firing an auxiliary rocket with the thrust vector oriented horizontal with respect to the earth's surface directly beneath, the elliptic orbit can be changed into a circular one.

Two critical steps are involved in guiding a satellite on its orbit. They are the generation of the correct velocity vector at the end of boost and the correct acceleration vector at the apogee point in the ellipse of ascent. The velocity vector is correct if the speed at the end of boost is as predicted, if it is parallel to the plane tangent to the earth directly underneath, and if it has the prescribed azimuthal direction. The acceleration vector is correct if the magnitude of the applied force and its duration is as prescribed and if it is in the plane of the orbit and parallel to the surface of the earth beneath.

The intelligence signals required for programming the satellite are the velocity vector at perigee and apogee, the time for these events, the altitude above the earth at perigee and apogee, and the computed speed for a circular orbit at the attained altitude. The missile must be instrumented to measure these functions and compute the duration and magnitude of the power to be applied by the auxiliary rocket propulsion motor.

● ● Missile Development Stages

The steps necessary for the development and introduction into use of a guidance system are similar to those used in many other electronic developments. There are, however, some differences which are associated mainly with the fact that the missiles meet unusual environmental conditions and that the equipment must have a high degree of reliability for its short-life, one-time operation. The missile itself is only a cog in a greater machine. It must mesh with other related equipment to form a major weapon system. The overall objectives and requirements for the system must be considered at all stages in the development.

The usual steps taken in the development of a guidance system are shown in the chart of Figure 12. The chain of events starts with the military requirements and ends with the introduction into use by the military departments. There are four broad phases involved: (1) research and development, (2) product engineering and prototype production, (3) production engineering and production, and (4) service evaluation and introduction into service use. The place of simulator investigations to verify the performance during the growth cycle is indicated by a separate loop. This technique is of extreme importance in studies on guidance systems. The component development is also highlighted here to show its importance and to indicate

that such development is usually parallel with other work on the system.

Advances in engineering technology are continuously coming into use. The replacement of vacuum tubes by transistors aids in the design from the standpoint of reliability, and also saves space, weight and electrical power. Gyroscopes with smaller drift rates, magnetrons with a higher power rating, printed electric circuits or microwave plumbing, new circuits for

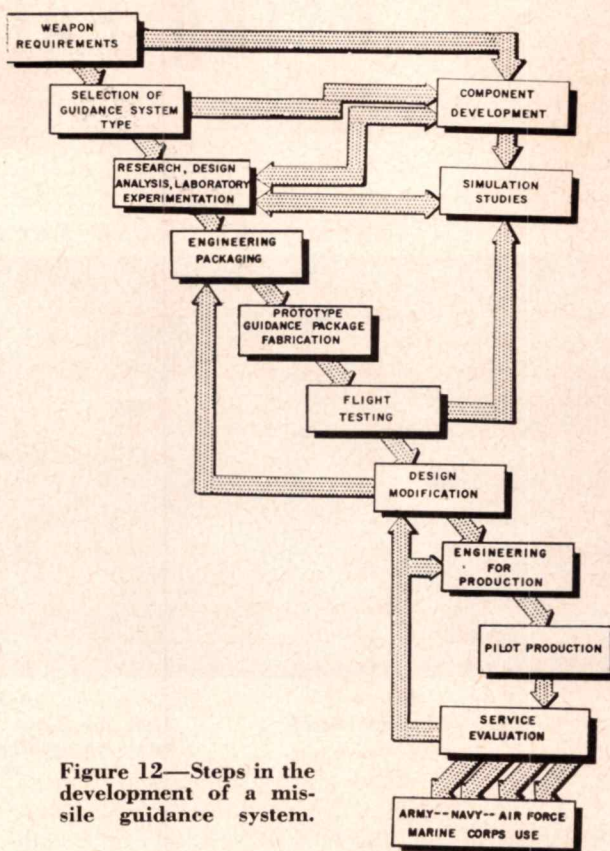


Figure 12—Steps in the development of a missile guidance system.

stabilized power supplies represent new developments for improving the performance of guidance systems. New methods for hermetically sealing components and for mass-producing electronic circuits are examples of advances in the state of the production art to reduce fabrication costs and increase equipment reliability.

END

The authors have all worked on the development of missile systems and components for the Bureau of Ordnance of the U. S. Navy, and grateful acknowledgment is made for timely advice from several officers of the Bureau of Ordnance for their aid in the preparation of this article.

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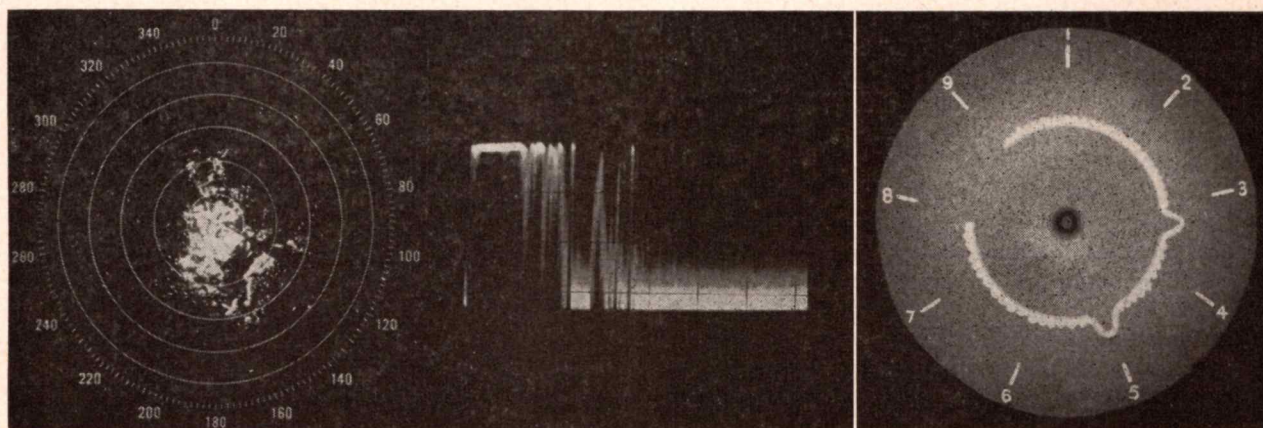
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While the technique of range measurement involves the measuring of minute time intervals, the selection of the best system depends on whether it will be manual or automatic, high precision or lightweight, and whether the targets will be moving rapidly or almost standing still.

RANGE MEASURING SYSTEMS Using Pulse Techniques

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COMMONLY USED RADAR PRESENTATIONS



PPI
Used on search radars.

A-SCOPE
Used for pulse and time measurements on oscilloscopes and synchroscopes

J-SCOPE
A circular sweep used on precision measuring equipment and for delay calibrators

THE DEVELOPMENT OF RADIO and radar techniques has made it possible to introduce a new dimension, namely time, into range measurement. The constant speed of electromagnetic waves, which can be measured to a high degree of precision, makes electronic distance measurements superior to most older methods.

The electronic principles that enable us to measure distance directly have become known only during the last 20 years. This article deals primarily with the fundamentals of range measuring using pulse techniques. The discussion is in terms of measuring range to passive targets that reflect transmitted energy such as radar. However, the information is equally applicable to transponder systems, such as beacons, DME or TACAN if the fixed known delay in the transponder is deducted from the measurement.

• • Time and Range

In a pulse radar, the range information is obtained by measuring the time interval between the transmitted pulse and the received echo. Consequently, the measuring procedure is equivalent to measuring time, since r-f energy travels at virtually constant velocity. Table I gives the numerical equivalent of time and

range based on the velocity of propagation of 299,673,000 meters per second in an average atmosphere.

Any radar system consists essentially of a transmitter that sends out radar pulses, a receiver for the returning echo pulses, and a measuring instrument to translate the time delay between the transmitted and returning pulses into a range measurement. In most radars, however, range measurements constitute but a portion of the overall task of detecting and tracking a moving target, and the circuitry involved in time measurement is closely linked with that of the automatic tracking loop. (A typical loop of this type is shown in Figure 5.) Here the video signal is obtained from the receiver, and the synchronizing pulse from the transmitter. The tracking loop will lock on any target video and track it in range until the target is lost or rejected.

The principal components of the tracking loop are the time discriminator, sweep generator and delay generator. Before the operation of the loop can be understood it is necessary to study the individual elements.

The time discriminator block is shown in Figure 1. The target echo pulse from the i-f amplifier is supplied to the video input. For the purpose of the following

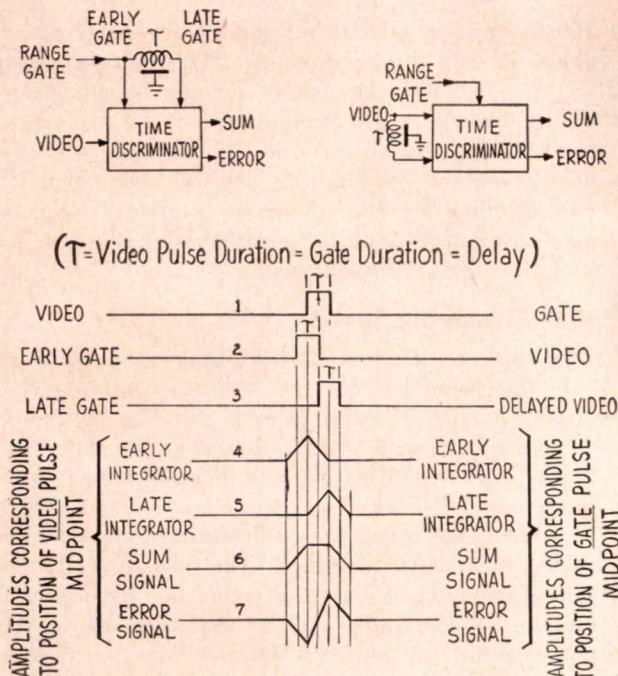


Figure 1—Time discriminator.

discussion, the video pulse width is τ microseconds. The early gate and late gate are two pulses of duration τ with a late gate delayed τ microseconds from the early gate. Therefore, the leading edge of the late gate coincides with the trailing edge of the early gate as shown in Lines 2 and 3 of Figure 1. The video pulse is tracked so that its duration is split equally between the early and late gates, as shown on Line 1.

The time discriminator is made up of four circuits. They are the early and late integrators and the sum and error generators. The early integrator produces an output that is proportional to the coincidence between the early gate and the video. On Line 4, the output of the early integrator is shown corresponding to the position of the video pulse midpoint, which is indicated by the arrow, relative to the early gate. Its output is a maximum when the early gate coincides with the video, and drops to zero when there is no overlap between them.

The late integrator is identical with the early integrator except that its output as shown on Line 5 is proportional to the coincidence of the late gate and the video. Algebraic addition of the early and late integrator outputs results in the sum signal shown on Line 6. Subtracting the output of the early integrator from that of the late integrator yields the error signal on Line 7.

The sum signal is relatively constant in amplitude and appears as long as the video signal coincides with one of the gates. Consequently, it is used in the system to stop the automatic search when the target has been found and causes the automatic search function to resume when the target is lost.

The error signal has the typical discriminator S-curve characteristic. It has a negative output if the video signal occurs too early and a positive output if it

is too late. Therefore, the error signal is used to correct the timing so that the video is always split equally between the early and late gates.

As shown in the block diagram on the top left of Figure 1, the early and late gates can be produced by feeding a gate of duration τ through a delay line with a delay of τ microseconds and using the delayed and undelayed pulses as the early and late gates. Sometimes, instead of delaying the gate, the video is delayed as shown in the block diagram on the top right of Figure 1. The action is identical with the case described above except that the legend on the right side of Figure 1 serves to identify the wave shapes. One may, therefore, consider the delay line part of the time discriminator, whether it is used to delay the video or the range gate. Consequently, the time discriminator block is drawn as shown in Figure 2.

• • Delay Generator

The delay generator shown in Figure 3 is sometimes called a time modulator. The inputs to the delay generator are a synchronizing pulse from the r-f pulse transmitter and the range voltage. Its output

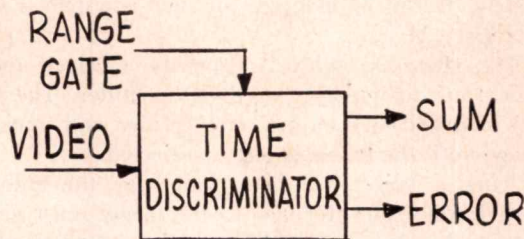


Figure 2—Time discriminator block.

is a delayed pulse which is used as the range gate in the time discriminator. The delay between the synchronizing pulse and the delayed pulse is controlled by the range voltage. The diagram of Figure 3 shows that as the range voltage is varied between E_1 and E_2 , the delay varies from $t=0$ to that corresponding to the maximum range of the tracking system.

• • Sweep Generator

The sweep generator and its timing diagram are shown in Figure 4. The inputs to the sweep generator are the sum and error signals obtained from the time discriminator. Its output is the range voltage used in the delay generator. In the absence of a target, the sweep generator produces a voltage sawtooth varying between E_1 and E_2 . The duration of the voltage sweep may be a fraction of a second or several seconds depending on system parameters such as pulse duration, maximum range and PRF (pulse repetition frequency). This mode of operation is shown as "search." When the gates encounter a target, the sum voltage appears and stops the voltage sweep. As long as the sum voltage is present, the sweep generator stays locked on the target. If the target moves, the

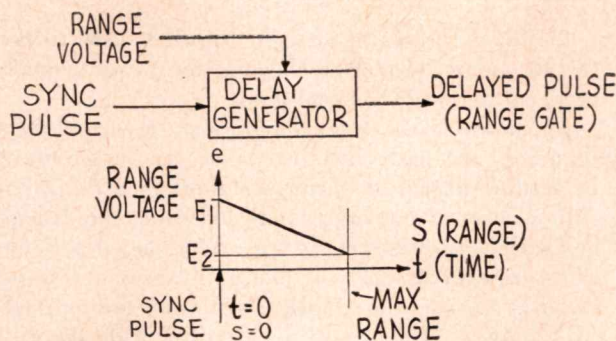


Figure 3—Delay generator, time modulator.

resulting error voltage causes the range voltage to change in such a manner that the gates will track the target. If the target is lost, the sweep generator resumes its sweep until another target is found. In case the sweep generator locks on the wrong target, it is possible to unlock the tracking system by rejecting it either manually or by some automatic sensing device.

● ● Tracking Loop

The time discriminator, sweep generator and delay generator can be connected together to form a tracking loop for an automatic time (or range) measuring system. The block diagram for such a system is shown in Figure 5.

The video is obtained from the receiver and the synchronizing pulse from the transmitter. The tracking loop will lock on any target video and track it in range until the target is lost or rejected.

After a target has been found by the automatic system, the exact distance to the target must next be extracted. There are various schemes to read this range.

When high precision is not required in the range measurement and where an accuracy of one part in

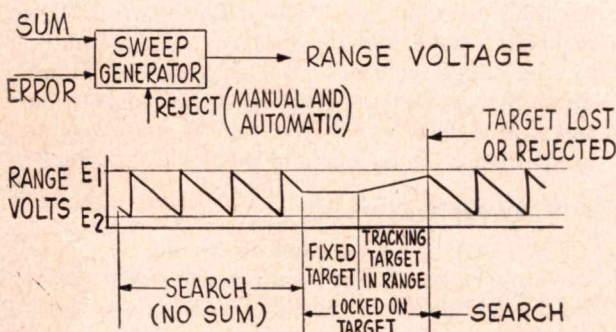


Figure 4—Sweep generator.

100 or one part in 200 is sufficient, the range can be obtained from the range voltage. This voltage, within the above limits of accuracy, can also be supplied to a computer. For instance, in airborne DME equipment the stated range accuracy is one mile on the 40 mile range and six miles on the 200 mile range ($\frac{1}{2}$ mile or three percent, whichever is greater). For an application such as this, the range voltage out of the sweep generator is monitored.

● ● Measuring Speed

In some applications it is desirable to measure not only the range but also the velocity of the tracked target. As can be seen from Figure 3, each range voltage e corresponds to a distance s . By definition, the velocity $v = ds/dt$. Since s is proportional to e , the velocity $v = k(de/dt)$, where k is a constant. Therefore, the range voltage e is differentiated and then amplified in a linear amplifier. The polarity of the resulting voltage will indicate whether the distance is increasing or decreasing, and its amplitude will be proportional to the velocity. This voltage can now be displayed on a meter similar to the range voltage, or it can be supplied to a computer.

● ● Precision Distance Measuring

Precision distance-measuring equipment generally uses a multiple scale measuring system. Two-scale measuring systems using a rough range and fine range control are the most common. Probably the best known two-scale scheme is the Meacham range unit. For the discussion of this unit refer to Figure 6.

The output of a coherent precision oscillator, shown on Line 2, is phase locked to the transmitter pulse, shown on Line 1. This could be accomplished using a gated oscillator. However, because of the required precision, a crystal controlled oscillator is generally used and allowed to operate continuously. The repetition rate of this system is then synchronized with the oscillator.

The output of the oscillator is phase shifted in a resolver or a phase shift capacitor. Either of these devices can be used to shift continuously the phase of the oscillator voltage and to determine the amount of phase shift precisely from its shaft position. The phase shifted sine wave on Line 3 of Figure 6 is used to trigger pulses which remain locked to the phase shifted sine wave. These phase shifted pulses on Line 4 serve as the fine control of the range measuring system.

The rough range control of the system is a delay generator, Line 6, which is identical to the one de-

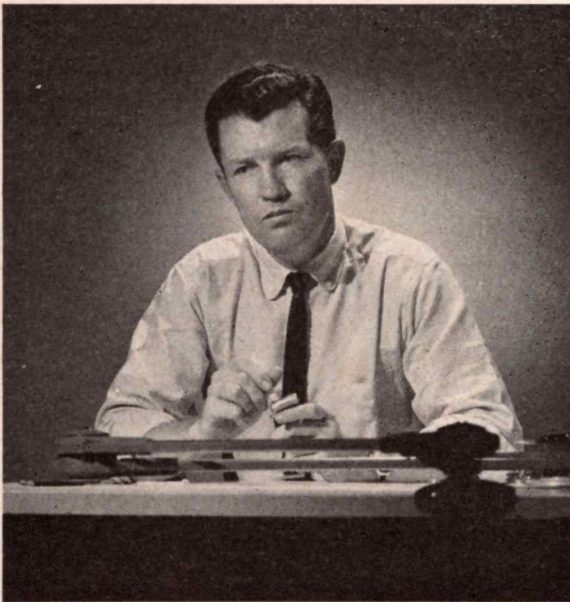
TABLE I—NUMERICAL EQUIVALENTS OF TIME AND RANGE

Meters	Yards	Nautical Miles
6.674×10^{-9} seconds/meter	6.103×10^{-9} seconds/yards	12.43×10^{-6} seconds/naut. mile
149.8 megacycles = 1 meter/cycle	163.9 megacycles = 1 yard/cycle	80.44 kilocycles = 1 naut. mile/cycle
149.8 meters/microsecond	163.9 yards/microsecond	80.44 naut. miles/millisecond

(Based on $c = 299,673,000$ meters per second)

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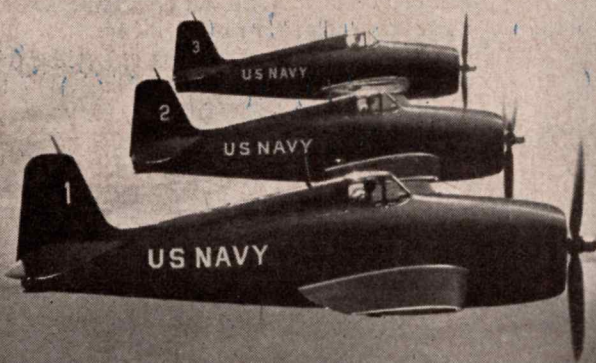
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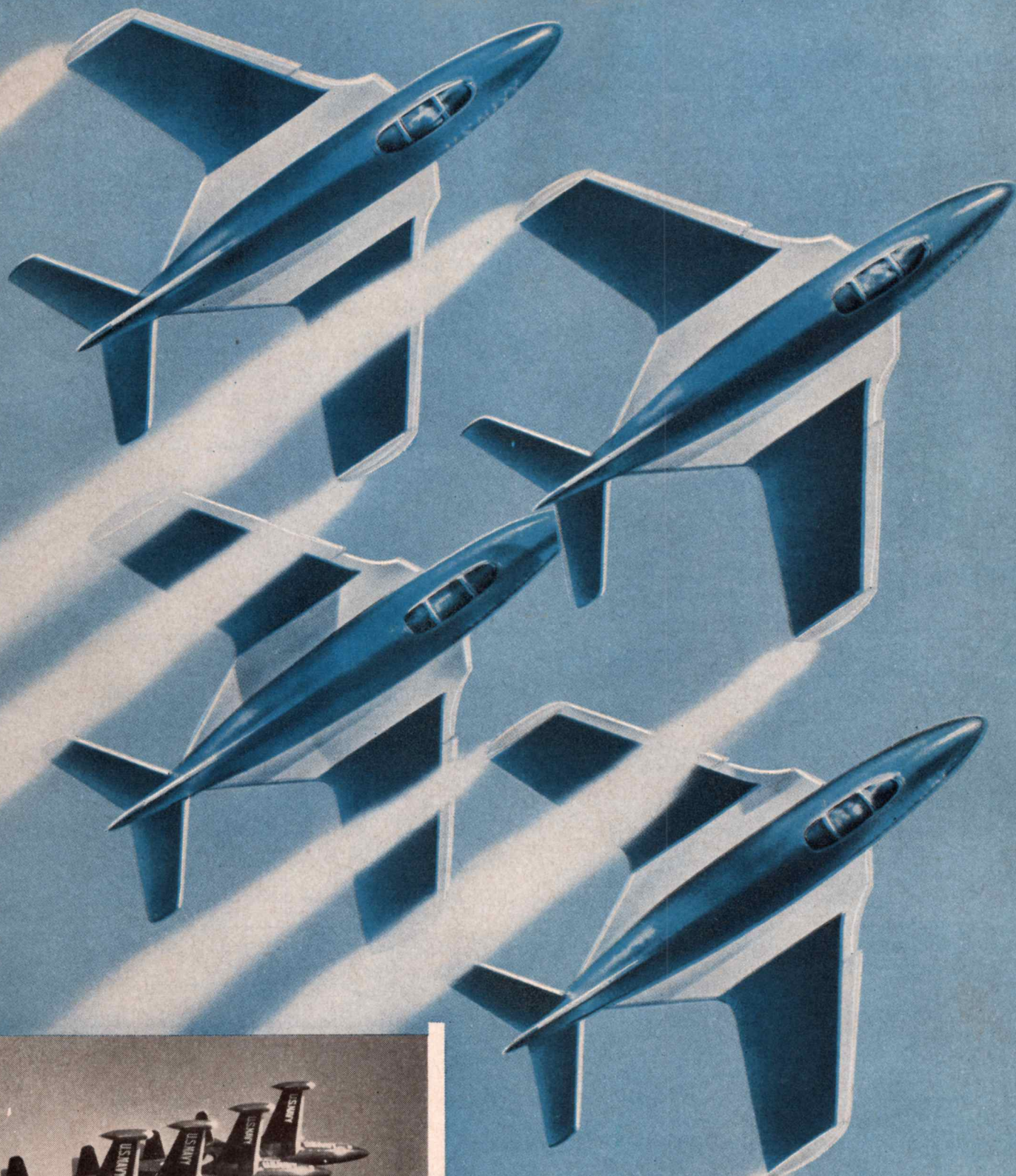
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scribed in the typical tracking loop. The delayed pulse from the delay generator is used to trigger the coincidence gate, Line 7. The duration of this gate is slightly shorter than the time delay between adjacent phase shifted pulses on Line 4. In this manner, the coincidence gate coincides in time with only one of the phase shifted pulses. The range voltage, Line 5, for the rough delay generator is obtained from the range voltage potentiometer which is geared to the phase shifter. The gearing between these two is arranged in such a manner that, as the handwheel in Figure 7 is turned, the delay generator output will increase its delay at the same rate as the phase shifted pulses. Therefore, as the phase shifter-potentiometer mechanism is rotated, the coincidence gate will track one of the phase shifted pulses. The phase shifted

delay generator replaces the sawtooth voltage output of the sweep generator. In the absence of a target, the servo motor causes the delay generator to sweep through the effective range. When a target video coincides with the range gate, the sum signal stops the sweeping action and the error voltage fed to the servo amplifier causes the gate to track the target. The target range is read from the range counter geared to the delay generator. A system similar to the one described above is used in the range measuring device of the airborne TACAN unit.

If several target echoes may be encountered, the phase shift device, the range potentiometer, the range counter, the servo motor and the entire gear train connecting them must be stopped before the range gates have passed the target. Because of the large

TABLE 2—POWER DISSIPATION IN COUNTER DECADES

Counter Decade Max. Counting Rate	Typical Power Input Requirement		
	+250V	6.3V AC	Total Dissipation
10 kc	6.5 ma	1.2 A	9 w
100 kc	14 ma	1.2 A	11 w
1 mc	75 ma	1.8 A	30 w
10 mc	185 ma	5.4 A	80 w

pulse under the coincidence gate is used as the precision delayed output pulse, Line 8.

Since the delay of the Meacham range unit is a function of the shaft position, a mechanical range counter can be geared to the assembly so that the delay can be read directly.

● ● Precision Delay Generator

The precision delay generator can be used as a manual index to read the delay and consequently the range to the desired target. The operator adjusts the delay until the precision delayed output pulse coincides with the desired target. He can then read the exact target range from the mechanical range counter.

An automatic ranging system using a precision delay generator is shown in Figure 8. Its operation is similar to the typical automatic tracking loop in Figure 5. The delay generator is replaced by the Meacham delay generator. A servo amplifier and servo motor replace the sweep generator. A mechanical link between the servo motor and the Meacham

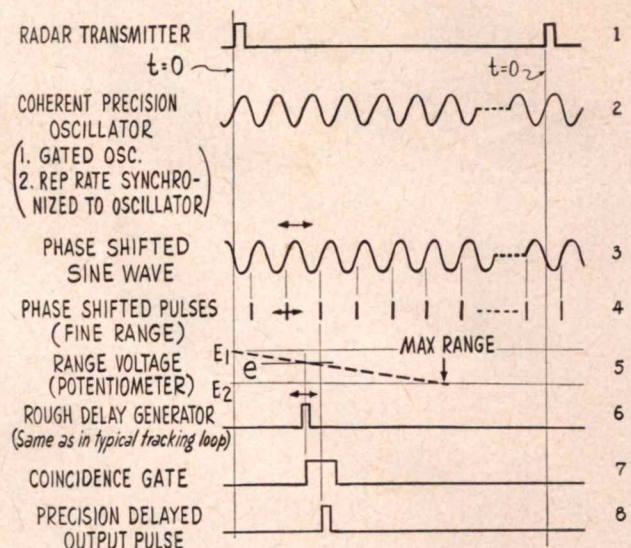


Figure 6—Meacham range unit timing diagram.

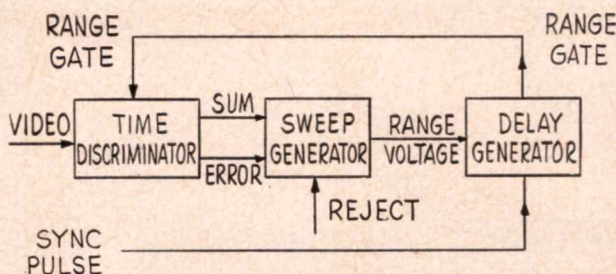
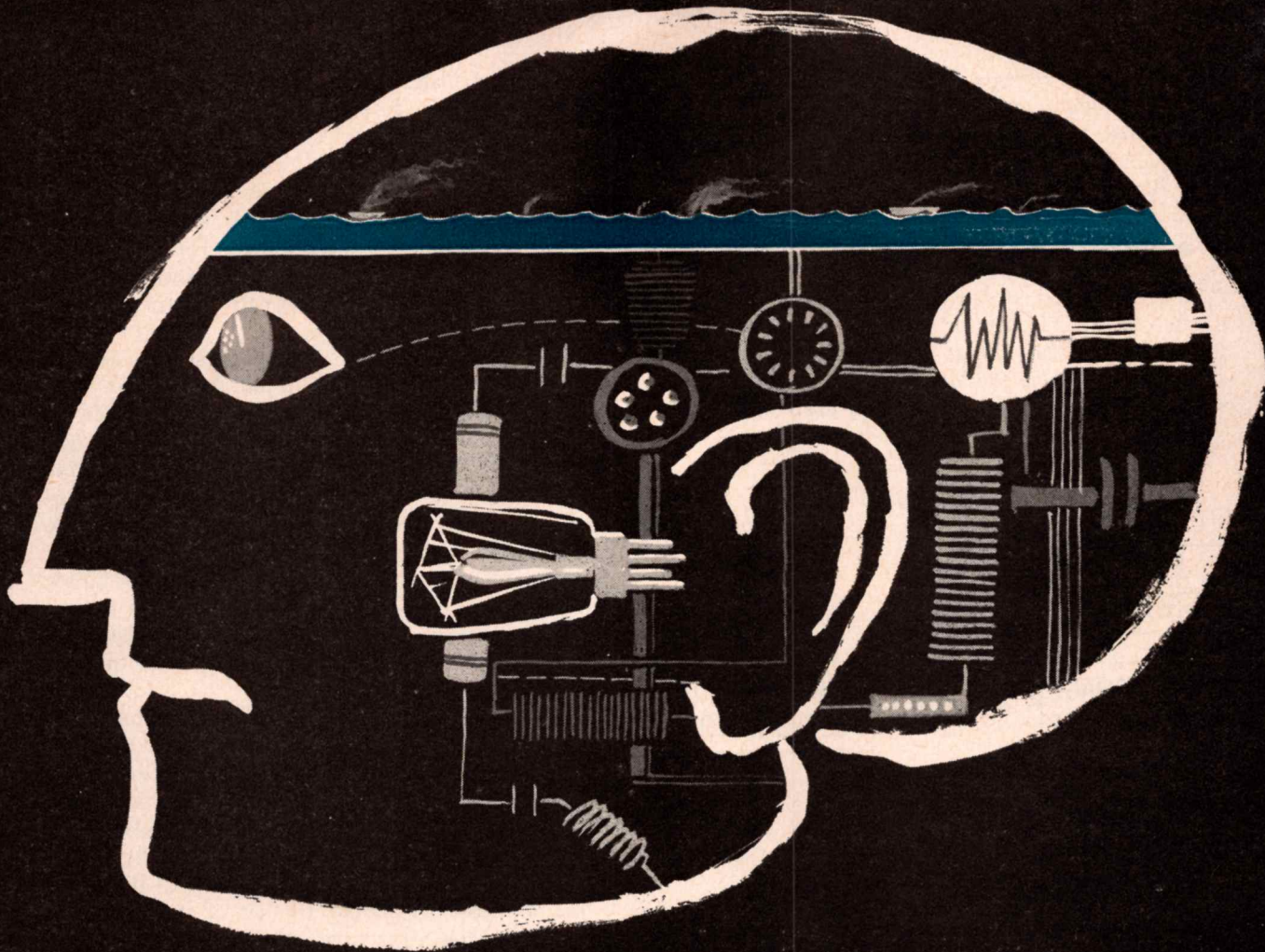


Figure 5—Typical tracking loop for automatic time measurement system.

inertia in an automatic range unit of this type, the search sweep must be relatively slow.

If a rapid search is required, a double loop system can be used. An automatic tracking loop similar to Figure 5 is used to search rapidly and to lock on the target video from the receiver. A sample of the range gate is then fed to the video input of the second loop similar to Figure 8. Since only one gate from Loop 1 will ever be present, the range gates of Loop 2 can be made quite wide. Consequently, the second loop can also be made to search rapidly, since the system can be allowed to overshoot an amount equal to the range gate width, remain locked, and still receive a



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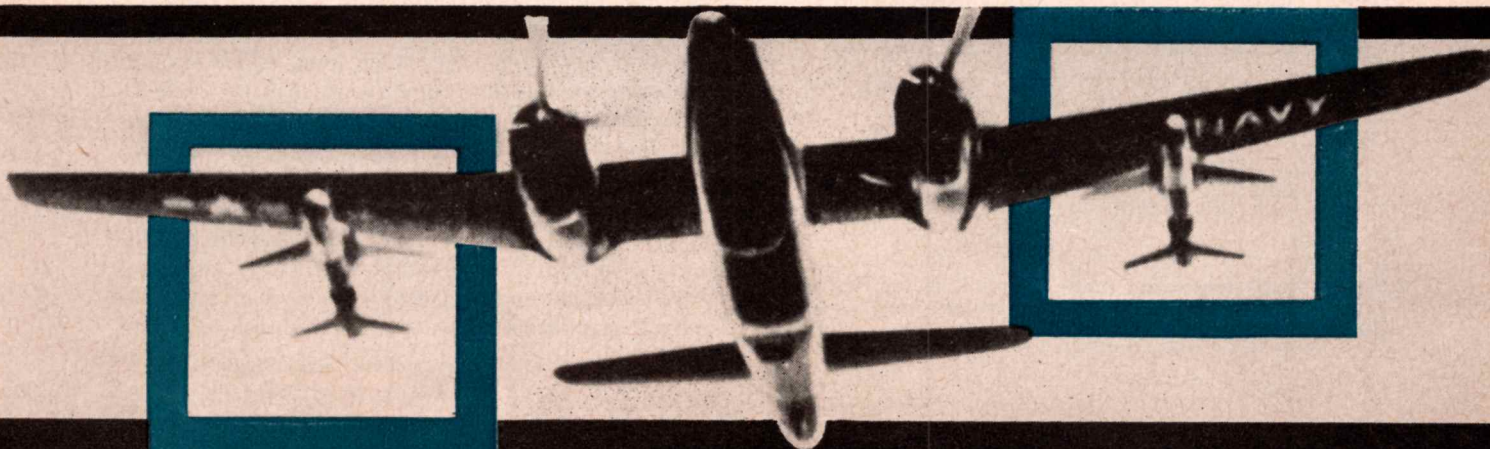


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correcting error voltage. The range is again read from the range counter geared to the precision delay generator. Any tracking error between the range gates and the video may be twice as great in this system since two tracking loops are involved.

● ● Systems Using Circular Sweep

A system used frequently to measure range accurately uses a circular or J-sweep on a cathode ray tube (CRT). The output of a coherent oscillator, similar to the one in the Meacham range unit, is phase shifted by 90°. When both phases are connected to

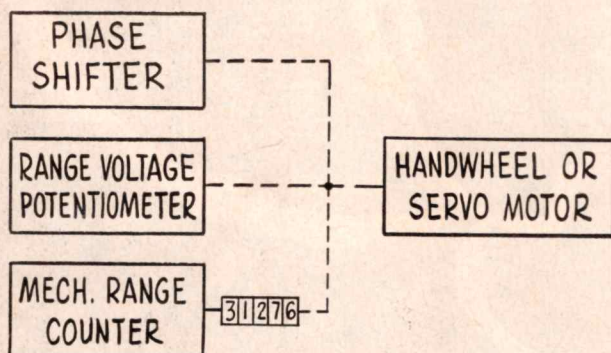


Figure 7—Meacham range unit.

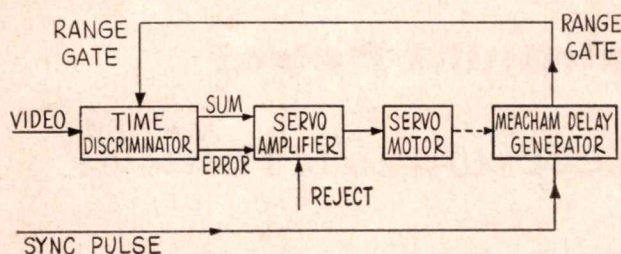


Figure 8—Automatic tracking loop using the meacham range unit.

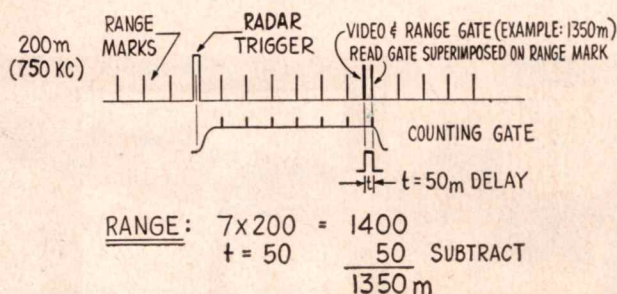


Figure 9—System using range marks I. Delay the read gate, from the range gate, to superimpose it on a range mark.

the deflection plates of a CRT, a circular sweep results. A convenient frequency is chosen for the oscillator such as 163.9 kilocycles so that each cycle corresponds to 1000 yards of range. An overlay on the face of the CRT is then marked off in 100 equal intervals corresponding to 10 yards in range. This is used to determine the fine range. The transmitter is locked to the oscillator and the phase adjusted so that transmission occurs exactly at zero on the overlay.

Since the sweep on the CRT corresponds exactly to 1000 yards, the zero point on the overlay corresponds to zero, 1000, 2000, 3000, . . . yards in range; the 180 yard mark on the overlay corresponds to 180, 1180, 2180, 3180, . . . yards. A delayed intensity gate slightly less than 1000 yards in duration is used to intensify only one sweep of the CRT. This delay can be obtained from the range voltage and serves to identify the 1000 yard sector of the target and yields the rough range. If the video from the receiver is connected to the center electrode of the CRT, the video results in a radial displacement of the circular sweep.

A delay generator similar to the one shown in Figure 3 is used to delay the start of the intensity gate. The range voltage used to control the delay generator can be measured and is used to determine the rough range, identifying the range sector intensified on the CRT. The fine range of the target is read from its position on the face of the CRT.

The operation is similar to that of the Meacham unit in that the fine range information is obtained by determining the phase shift of a precisely controlled frequency and in that the rough range is determined by the coincidence of the intensity gate (or the coincidence gate) with one cycle of the oscillator. The J-scope system differs from the Meacham range unit in that the phase shift is read from the face of the CRT, instead of shifting the oscillator frequency in a phase shift capacitor and reading the amount of phase shift from the shaft position.

● ● Systems Using Range Marks

Range marks and a variable delay to interpolate between them can be combined into a precise, two-scale measuring system. The range marks are obtained from a coherent range marks oscillator which is phase locked to the repetition frequency. For the purpose of illustration, a 750 kilocycle oscillator, generating 200 meter range marks has been chosen. Figure 9 shows the radar trigger which is made to coincide with one of the range marks. In the case of an automatic ranging system, the range gate, which occurs at the same time as the target on which it has locked, is delayed in a delay generator or an adjustable short delay line. The video or range gate, the delayed range gate (read gate) and the range marks are displayed on an expanded A scope. The operator adjusts the delay t until the read gate coincides with one of the range marks. The counting gate starts after the r-f transmission and is ended by the read gate. In Figure 9 the target video has been shown at 1350

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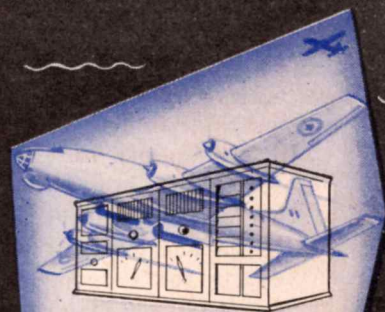
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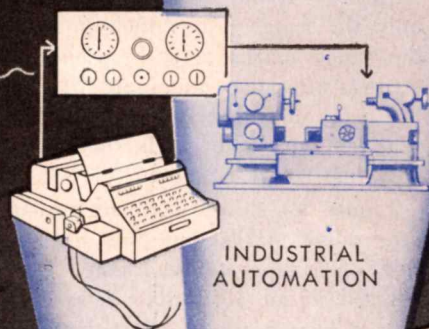
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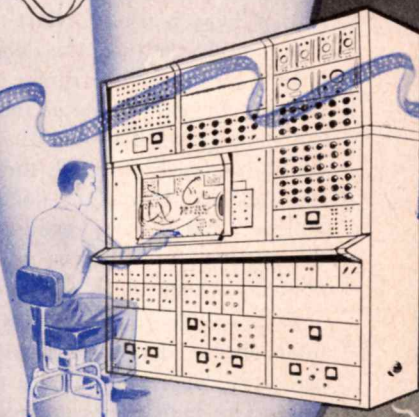
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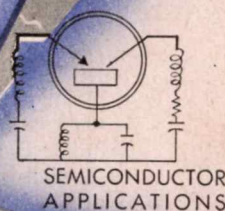
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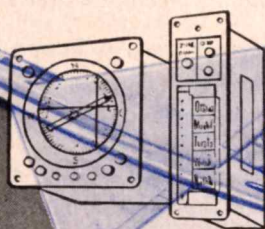
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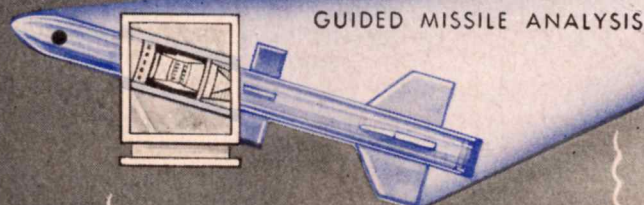
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meters. The counting gate admits seven range marks to an electronic counter, corresponding to 7×200 or 1400 meters. The short delay dial shows 50 meters. Subtracting the 50 meter reading from 1400 yields the target distance of 1350 meters.

The advantage of this system is that no phase splitter for a J-scope, phase shifter or resolver is necessary. The disadvantages of the above system are that the adjustable range gate must be superimposed on the next range mark following the target. This requires that the expanded A-scope must display not only the range sector including the target but also the range marks must be visible up to two micro-seconds after the range gate. Since the oscillator and the delay must be calibrated separately, the system is difficult to calibrate in the field if the distance to only one target is known.

Figure 10 shows a range measuring scheme that uses range marks, but does not require the generation of a separate read gate. The radar trigger is delayed in an adjustable delay line and at the end of this delay is used to start the range mark oscillator. The operator adjusts the delay t until the target coincides with one of the range marks. The counting gate starts at the same time as the oscillator and ends with the range gate. The counting gate admits six pulses. As shown in Figure 10, the target range can be determined by adding the delay t of 150 meters to 6×200 or 1200 meters, resulting in 1350 meters. While this system does not require a read gate, a gated precision range mark oscillator must be used.

Several other schemes using range marks and an interpolation delay are feasible. For instance, a continuously operating range mark oscillator can be used. The transmitter pulse is delayed from one of the range marks until the target coincides with a range mark, see Figure 11.

The start of the precision delay may be triggered by any selectable range mark as shown in Figure 12. This scheme was used in the British *Oboe* precision bombing system during World War II.

Instead of using a variable delay, the linear, delayed and expanded sweep of an A-scope can be used as in Figure 13. The operator adjusts the sweep delay until the range mark preceding the target is aligned with a line on the left of the A-scope overlay. The rough range to the range mark is determined

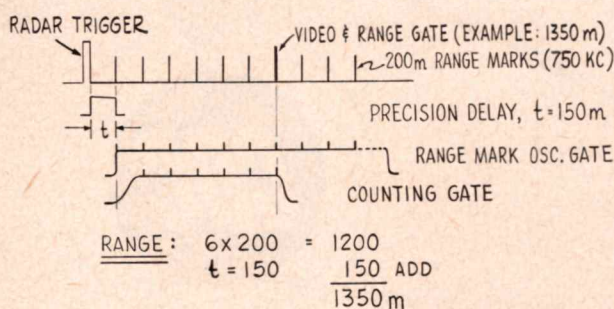


Figure 10—System using range marks II. Delay range marks, to superimpose one of them on the range gate.

from the delaying voltage. The fine delay between the range mark and the target is then read from the overlay.

● ● Systems Using Electronic Counters

Electronic counters can be used to measure the time delay between the transmitter pulse and the range gate. By using a suitable frequency and counting the number of cycles between these two pulses, the electronic counter can be made to display the range directly. For instance, if a frequency of 16.39 megacycles is used, each count represents 10 yards; for 8.19 megacycles, each count represents 20 yards.

Presently available commercial counters have a maximum counting frequency slightly above 10 megacycles. Since an unknown time interval is to be measured, heterodyning such as is used in measuring a frequency with counters cannot be utilized. The resolution of an electronic counter is ± 1 count, so that in the case of the 8.19 megacycle counter, the range resolution will be ± 20 yards. If the r-f pulse transmission is locked to the oscillator being counted, the resolution becomes $\pm \frac{1}{2}$ count or ± 9 meters. It may be possible with a suitable vernier to interpolate to $\pm 1/10$ count or ± 2 meters with an 8.19 megacycle counter if the transmission is locked to the oscillator.

The electronic counter has the obvious advantage of an instantaneous and direct read-out of the range. While counters with a slow maximum counting rate require very little current, the high speed decades have a large power consumption. A comparison of the power requirement of counter decades with various maximum counting rates is shown in Table II. Also, while slow speed counter decades are very stable, those operating above one megacycle are usually quite critical to operate and require stable, regulated, low impedance power supplies.

● ● J-Scope Versus A-Scope Display

The advantage of a J-scope is that a longer sweep can be obtained than on an A-scope for the same diameter tube. Also, the sweep of a J-scope can be made more linear than an A-scope sweep. Consequently, for the same diameter CRT the range can be read to a greater precision on a J-scope.

One disadvantage of a J-scope is that a special tube with a radial electrode is required. Also the

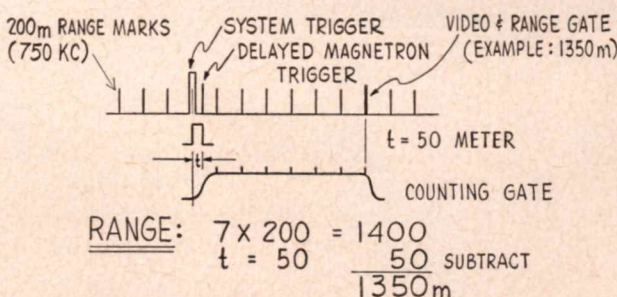
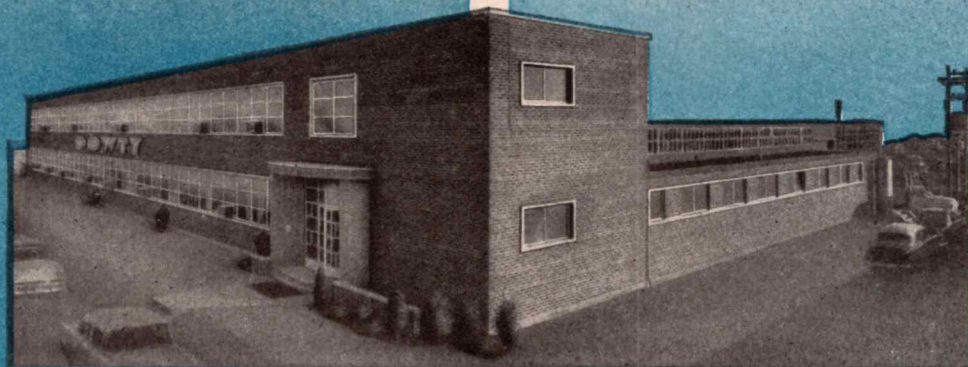


Figure 11—System using range marks III. Delay the transmitted pulse to superimpose the range gate on one of the range marks.

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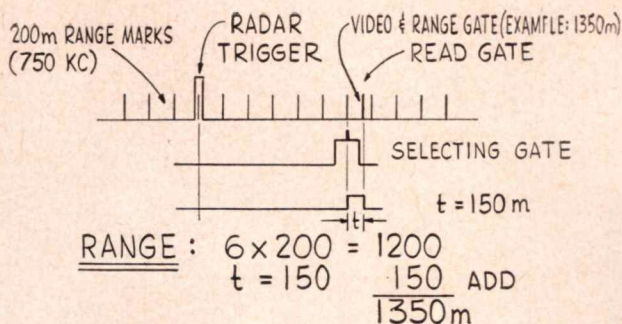


Figure 12—System using range marks IV. Precision delay triggered by any selectable range mark.

linearity adjustment is rather difficult, in that several interdependent adjustments must be made.

The advantages of an A-scope are that an expanded sweep of a range sector, and also, a full range sweep can be made available. Also, an A-scope is easier to understand for an untrained operator since range always increases to the right.

● ● Recognition, Selection and Resolution

Target recognition and selection becomes necessary when more than one target may be met at one time. The number of targets that may be expected determines the required resolution and consequently the early and late gate width. The total gate width must be smaller than the minimum distance between targets which the range unit is required to resolve.

The number of simultaneous targets may necessitate target identification. Pulse coding is frequently used for this purpose. Radar beacons, DME and TACAN utilize this technique.

Sometimes it is not feasible to have the desired target carry a transponder beacon or to expect it to transmit an identifying pulse. To provide target identification of non-transponding targets, antenna lobe-switching or conical scanning may be used. If a line of sight can be established to the target, it is possible to discriminate against all targets off the antenna axis. This is possible since all off-axis targets are amplitude-modulated at the antenna switching or scanning frequency.

Information obtained from antenna lobing, or conically scanning antennas can be used as servo data to track a target in azimuth and elevation. Since the error voltage supplied to the sweep generator causes tracking in range, complete three-dimensional tracking of the target is possible by this technique. The spherical target coordinates—azimuth angle, elevation angle and slant range—can be converted to rectangular coordinates in a computer, if necessary.

● ● Range Accuracy

The pulse width of the transmitter is a limitation on the absolute range accuracy. Table I shows that a five-microsecond pulse corresponds to 0.4 nautical miles and a one-microsecond pulse corresponds to 164 yards.

For range accuracies greater than one part in 100 or 200 of the maximum range, the read-out must be

in the form of a shaft position or as a displacement on a CRT. This is due to the fact that electrically controlled delay generators, such as sanatrons, are not linear enough; and even a precision meter will read the delay controlling voltage only to ± 1 percent or one part in 100. On the other hand, mechanical read-out devices if used excessively, for instance if they are motor driven to provide the target search, are subject to wear. To obtain a high degree of accuracy requires a multiple scale system.

Electronic counters have no limitations that can be expressed as a fraction of maximum range since the addition of a low frequency decade extends the maximum readable range by a factor of 10. The limitation that is found in electronic counters is that of resolution since the maximum resolution of a counter in yards is: $\lambda(\text{yards}) = 164/f$, where f is the maximum counting frequency in megacycles.

● ● Summary

Most range finding devices use a coarse and a fine (two-scale) measuring system if any precision greater

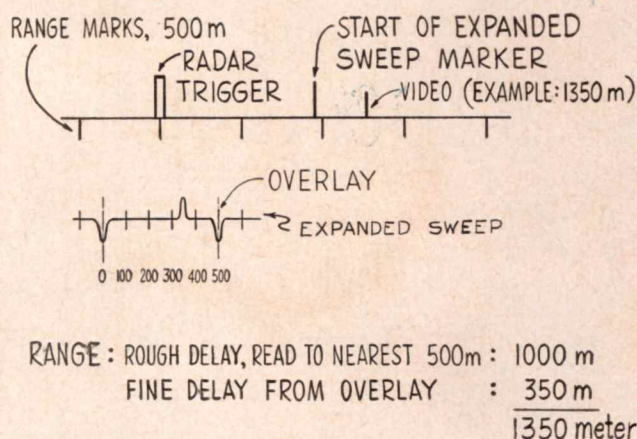


Figure 13—System using range marks V. A/R scope.

than one percent is required. The only exceptions are range finders using electronic counters.

Some two-scale systems use a delay generator such as a sanatron as the rough scale and the phase delay of a precisely controlled frequency as the fine scale. The phase delay can be read directly from a J-scope, or the phase delay can be varied by a known amount by some device such as a phase shift capacitor (Meacham range unit), a phase resolver or a variable delay line.

Other two-scale systems use range marks obtained from a crystal oscillator as the rough scale and interpolate between these range marks with a variable calibrated delay, such as a sanatron or a variable delay line, as the fine scale.

Using high speed electronic counters for range measuring is a new approach. This method appears promising, since low power-consumption highspeed counters may soon be possible using the new surface barrier transistors and magnetic storage elements, now under development.

END

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Flight Mechanics of THE SATELLOID

KRAFFT A. EHRIKKE

Chief of Preliminary Design
Convair Missile Division, General Dynamics Corp.
San Diego, California

THE ULTIMATE PURPOSE of space flight is to reach other celestial bodies and to explore their atmospheres, if any, and their surfaces. Descent from space is therefore an important phase of an astronomical exploration whose scope exceeds that of a temporary satellite operation. Most important, of course, is the descent to our own planet.

The velocities involved in this process require an entirely different approach from that for a high-altitude airplane descending into the denser layers of the atmosphere. Indeed, when a spacecraft hits the atmosphere of a celestial body, the condition of motion is changed as profoundly as that of a landing airplane at the moment the wheels touch the ground. Without exaggerating, it can be said that "landing" for a space vehicle means correct re-entry into the atmosphere rather than touchdown on the landing field.

For conventional airplanes, one prepares special landing sites, thereby establishing usual landing conditions for the airplane designer as well as for the pilot. The "landing site" for the incoming space ship is the upper atmosphere. We cannot of course change the prevailing conditions in this region, but we can and must explore them in order to adapt correspond-

ingly the design and flight operational concepts, and we must make this region familiar territory for the re-entering astronaut. These requirements establish a need for comprehensive exploration of certain regions of the upper atmosphere of the earth.

● ● Re-entry and Descent

Re-entry of a space vehicle involves the more or less shallow dive into the atmosphere, and the leveling off at the desired correct altitude. The subsequent descent is concerned with letting the vehicle down through the atmosphere. The problem here, which determines the flight path, is to minimize the influx of thermal energy into the outer skin of the vehicle. The unavoidable prevailing amount of heat determines the interior construction, whose purpose is to protect the inner, load-carrying structural members from excessive heating and to minimize the overall structural weight of the airframe.

The re-entering vehicle enters our atmosphere at a velocity of 17,500 mph (circular velocity) to 18,100 mph (when descending from a 1200 nautical mile high orbit). At such velocities aerodynamic forces are encountered at high altitude and in extremely rarified air, which are comparable to those experienced at conventional speeds on or near the surface. A relatively small error in re-entry altitude sends the aerodynamic forces soaring up at a high rate. Traveling at 60 mph on a highway produces a dynamic pressure of about 15 lb/ft², the same as that for a circular velocity motion at about 285,000 feet altitude. When riding in a commercial airliner at 300 mph at 20,000 feet, the dynamic pressure is the same as that

for a space ship moving at circular velocity 210,000 feet high. (The altitudes quoted may vary somewhat, since no complete agreement is yet reached regarding the exact density range at these altitudes.) The variation of the dynamic pressure with altitude acting on a body moving at local circular velocity is shown by the left curve in Figure 1. This curve illustrates the rapid increase in dynamic pressure with decreasing re-entry altitude. If the ship, coming in from several

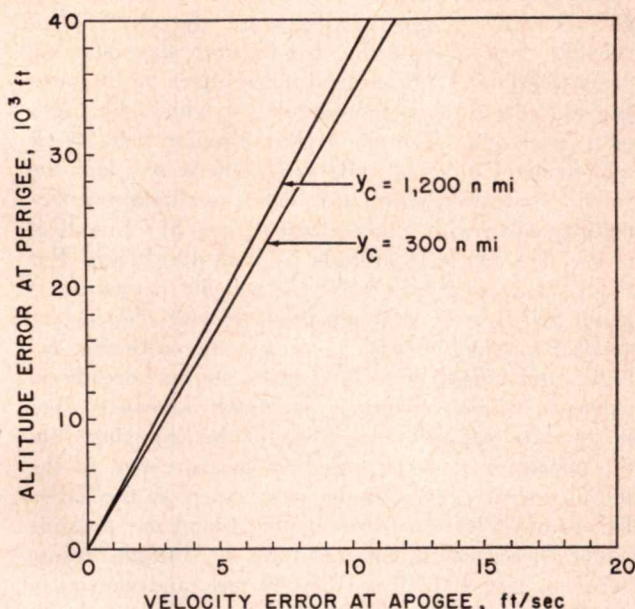


Figure 2 — Effect of velocity error at departure from satellite orbit (apogee) on perigee altitude.

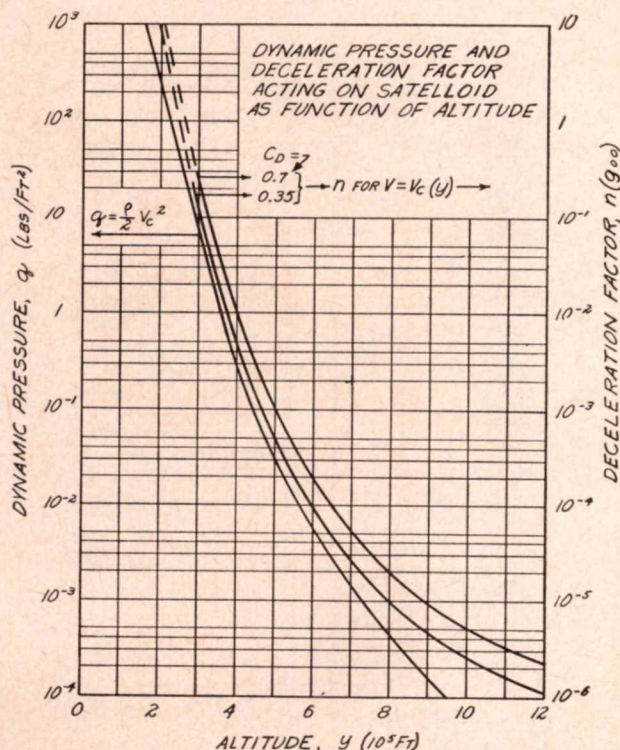


Figure 1

million feet altitude and destined to level off at 250,000 feet altitude, is in error by 100,000 feet (which would constitute a fairly large error), the dynamic load would soar from 30 to 1000 lb/ft².

By the same token, the *g*-load, acting on structure and crew, would climb rapidly. The two curves on the right hand side of Figure 1 show how the *g*-load (ordinate on the right), as a result of deceleration, varies with altitude, for circular velocity, assuming two drag coefficients, 0.35 and 0.70. It should be noted that by varying the drag coefficient, the pilot could relieve the load on vehicle and crew. For this reason a basically slender, low-drag body design appears desirable, a design that can be converted into a high-drag configuration (drag due to lift) by varying the angle of attack. This provides the pilot with a certain amount of flexibility that he would not possess in a high form-drag design, such as a very blunt plumb shape or a spherical body.

Finally, the error in re-entry altitude would increase the thermal load rapidly (approximately in proportion to the square root of the pressure rise). Even if the steady state capacity of the outer skin were not exceeded by this thermal onslaught, the transient effect, known as thermal shock resulting from a sudden increase in heat flux density, would be likely to have a

Satelloid

serious effect on the structural rigidity of the vehicle and its capability to withstand subsequent heat loads.

Thus, it is not only important to follow the correct re-entry path but also it is necessary to place the level-off altitude high enough to allow for a practical margin of error. Figure 2 illustrates the effect of a velocity error in departing from a (circular) satellite orbit (300 and 1200 nautical miles high) on the perigee altitude, that is, the altitude at which the flight path levels off. The theoretical circular velocity at 300 nautical miles altitude is 24,896 ft/sec, and the velocity reduction required to enter an elliptic transfer orbit to earth with a theoretical perigee at 50 nautical miles (304,000 feet) altitude is about 450 ft/sec. For the 1200 nautical mile orbit the velocity decrement is about 900 ft/sec. Although these velocity changes are small, the velocities with respect to the earth are still high; and unless there is a space station already in existence whose velocity is accurately known so that it can serve as a reference point for the departing ship, the maneuver must be based on measurement of the initial velocity and altitude with respect to the earth. Errors of at least a few feet per second are possible under these conditions, resulting in altitude errors between, say, 10,000 and 30,000 feet, and causing a density variation by 50 to 250 percent. If the velocity change is low by so many feet per second, the re-entry altitude will be too high; in the opposite case, the altitude will be low by so many feet, resulting in a corresponding increase in density.

If the originally planned altitude is sufficiently high, such an increase is not necessarily detrimental, because the absolute density is small. An increase in dynamic pressure from 1 lb/ft² to 1.5 or 3.5 lb/ft² is not very significant. However, if the re-entry altitude is placed low, say at 250,000 feet with 50 lb/ft² dynamic pressure, the same error may produce dynamic pressures from 75 to 175 lb/ft². Such pressures would greatly alter the vehicle's path, since lift forces are involved, and would excite flight path oscillations leading to even greater loads or to destruction during the subsequent dive.

Higher altitude is therefore desirable, and it appears that the level-off altitudes should be of the order of 300,000 feet or higher, depending somewhat on the distance in space from which the returning vehicle comes in. This may, in some cases, result in one or more additional "braking" ellipses before the re-entry process is completed and the vehicle begins to descend.

In general, the altitude between 300,000 and 600,000 feet and, in a more restricted sense, between 300,000 and 400,000 feet can be regarded as the "gate to the atmosphere" where aerodynamic forces begin to act on incoming vehicles.

Obviously, the significance of these atmospheric regions requires a thorough knowledge of all relevant conditions during all seasons and at all latitudes. Among the interesting research subjects are information on density, temperature, air composition, degree of ionization (electron density) and the variation of these qualities day and night and as function of solar activity. Of equal importance is the exploration of the upper atmosphere dynamics, that is, winds and gust conditions which may be of thermal or electric origin.

A systematic exploration of individual strata requires a number of revolutions along great circle

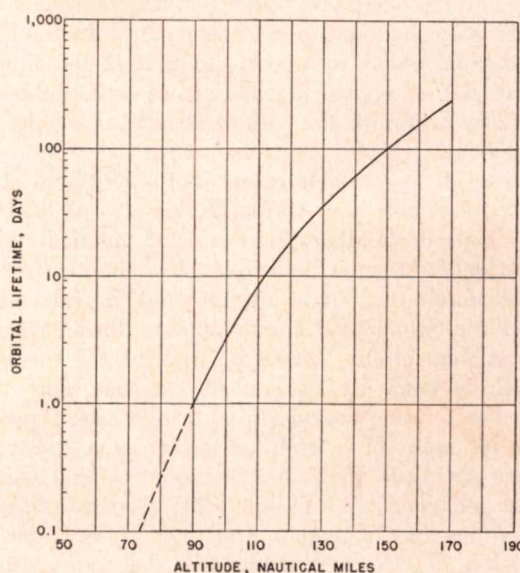


Figure 3—Orbital lifetime of a spherical satellite. ($C_D = 2.2$, $W/A = 30 \text{ lb/ft}^2$)

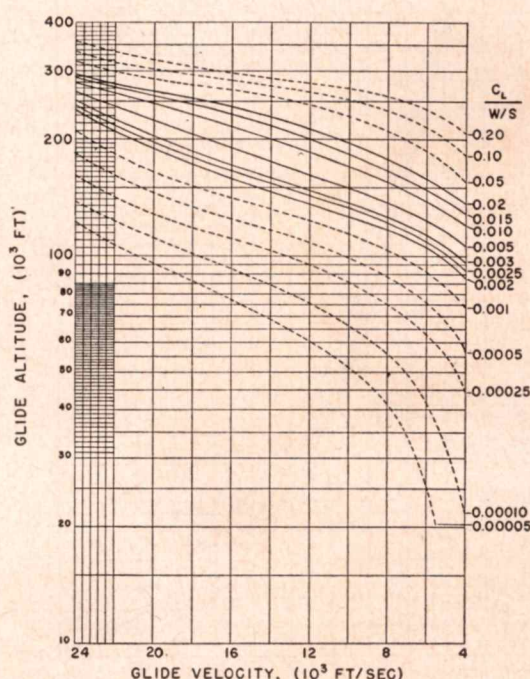


Figure 4—Glide altitude versus flight velocity as function of the lift parameter.

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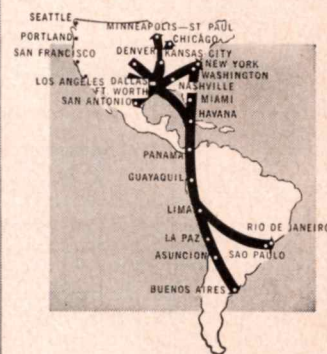
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Satelloid

paths. Can instrumented satellites help furnish this information? They can only to a limited extent, that is, at the outer fringes of this threshold region. The establishment of satellites requires a certain minimum altitude to make sure a nearly constant-altitude orbit is followed for a number of revolutions. Since the satellite operates under the influence of gas-dynamic forces, not only the altitude (density, dynamic pressure) affects the orbital behavior, but also the drag coefficient C_D and the density of the body, expressed in terms of weight over cross-sectional area, W/A . In the altitude region above 300,000 feet the drag coefficient is fairly constant and is about 2.2 for a spherical body. Figure 3 shows for a fairly dense satellite of $W/A = 80 \text{ lb/ft}^2$ how the orbital lifetime varies with altitude. The orbital lifetime is defined as the period required by the satellite to spiral down from its original orbit to an altitude of about 80 or 90 nautical miles when the perturbation due to drag becomes so strong that the path can no longer be regarded as a true orbit and the final dive into the denser atmosphere begins to develop. It can be seen that below 100 nautical miles, and particularly below 65 nautical miles (about 400,000 feet), atmospheric exploration by means of satellites is no longer satisfactory.

A method of operation more suitable for lower altitudes is the hypersonic glide. However, rocket-powered

boost-glide vehicles will operate at altitudes below 300,000 feet. This is shown in Figure 4, which relates glide velocity and glide altitude for a number of lift parameters $C_L/(W/S)$, where C_L is the lift coefficient and W/S the lifting area load of the glider.

● ● Satelloid Operation

Thus, between roughly 300,000 and 600,000 feet altitude there is a region too high for glider vehicles because of too high a rarefaction of the air and because of very unfavorable aerodynamic conditions; and too low for satellites, because the air is not yet sufficiently rarefied to permit an adequate orbital lifetime.

However, the drag force and the deceleration involved are quite small, as Figure 1 indicates; it is rather the extended time period and the self-accelerating nature of the spiral-in process that forces the satellite down. Only a minute thrust force is required to counteract the drag force and to maintain the orbit as though it were in vacuum.

A vehicle moving at this altitude range would then have to operate under a small but sustained thrust power. The high speed and the low amount of thrust required make it possible to operate through a significant number of revolutions. The vehicle can follow a circular orbit at circular velocity, like a satellite. However, the motion under power represents a significant difference from a satellite. Therefore, the designation *satelloid* is suggested for such a vehicle.

The performance requirements for a satelloid moving at circular velocity can be analyzed quite easily,

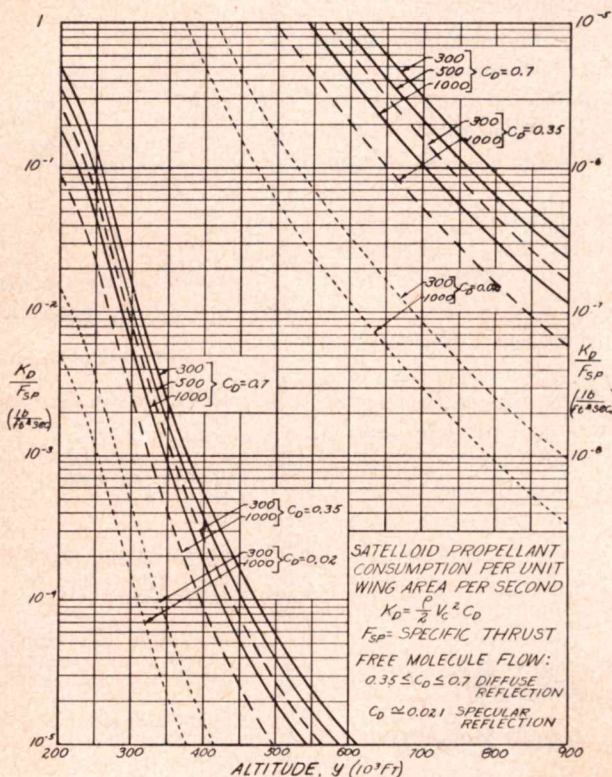


Figure 5

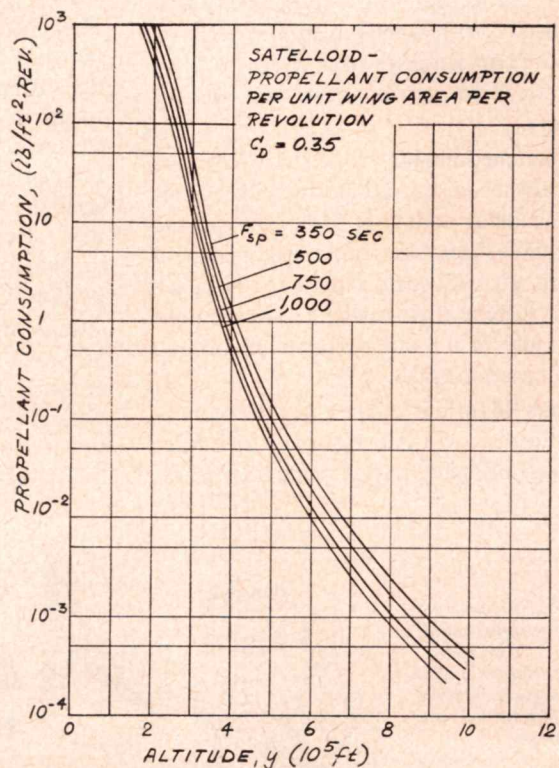
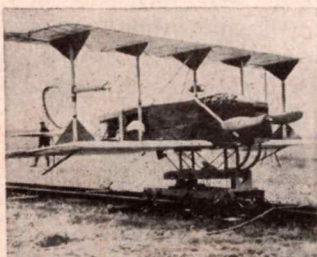


Figure 6



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Satelloid

Reference 1. Figure 1 shows that for a given altitude and speed the deceleration in g -units, that is, the ratio of drag to weight, is only a function of the drag coefficient, which in this case is given with respect to the wing area rather than the cross-sectional area. The drag is therefore equal to the product of dynamic pressure, drag coefficient and wing area. Since the thrust must be equal to the drag, if constant velocity and altitude are to be maintained, the thrust is directly proportional to the wing area of the vehicle; and since the thrust is proportional to the propellant consumption per second, it follows that one can draw a general plot, showing the propellant consumption in lb/sec/ft^2 wing area, qC_D/F_{sp} , where q is the dynamic pressure and F_{sp} the specific thrust, that is, the thrust obtained from the engine per pound of propellant per second. This plot is shown in Figure 5 for specific thrust values of 300, 500 and 1000 lb-sec/lb , and for three values of the drag coefficient. A specific thrust of 1000 cannot be obtained with chemical rocket engines and has been added here only for reasons of comparison. Of the drag coefficients, the smallest, $C_D = 0.021$ refers to a special flow condition near the walls of the vehicle, known to the aerodynamicist as specular reflection. This means that the individual molecules hitting the surface in this rarefied gas flow like bullets spraying an armored plate and are reflected at the same angle by the wall as they move

toward the wall, like a light beam that is reflected by a mirror. The condition is much like that of a tennis ball bouncing off a smooth pavement. As with the pavement, only to a greater extent, the vehicle wall has to be smooth to cause the molecules to be reflected specularly. In fact, no technical surface known today can be made smooth enough to produce such effect. This is regrettable, since specular reflection yields much higher lift than the alternate type of reflection, designated as diffuse reflection. This process can be illustrated by the bouncing of a tennis ball when thrown on rough cobblestone pavement. The ball may bounce in any direction. Many of these reflections do not add anything to the lift, but only to the drag.

For a returning space ship, drag at high altitude is desirable, because it brakes the speed at altitudes where the transfer of heat into the skin is still small. But high lift is also desired, in order to keep the vehicle at high altitude as long as possible, until a maximum of velocity reduction is attained. Although in practice some specular reflection will occur, the bulk of the molecules will be reflected diffusely so that it is more realistic to assume diffuse reflection.

Knowing the consumption per unit wing area and for a given drag coefficient, one can plot the consumption per unit wing area and revolution, since, for circular velocity, altitude and period of revolution are uniquely correlated. The resulting propellant consumption per revolution around the earth and per unit wing area is shown in Figure 6 for $C_D = 0.35$ and for different specific thrust values. It is interesting to note that the effect of altitude is considerably stronger than the effect of an increase in specific thrust. At altitudes in excess of 400,000 feet, variations in specific thrust are no longer very important, unless long periods of operation are considered. In general, the propellant consumption required to sustain a satelloid in its path for a full circumnavigation of the earth is extremely low for altitudes above 300,000 feet. Therefore, several revolutions, even as many as 10, 20 or more, seem feasible during one flight operation of the satelloid.

● ● Example of Satelloid Flight

With the data on hand, it is now simple to compute an example. Assume a winged satelloid of 10,000 pounds empty weight and a wing area of 500 ft^2 , so that the empty wing loading is 20 lb/ft^2 . The drag coefficient is 0.35 and the specific thrust 350 lb/sec/lb . Figure 7 then shows the propellant consumption per revolution $\dot{W}_r$, the initial weight W_0 , the initial wing loading W_0/S (S = wing area), and the mass ratio W_0/W_e (W_e = empty weight), required for one revolution. Assuming the vehicle carries initially 5000 pounds propellant on board, certainly not a very large quantity (mass ratio 1.5), it is capable of 1 revolution at about 330,000 feet altitude, 10 revolutions at 410,000 feet, 100 at 520,000 and 1000 revolutions at 670,000 feet. With one revolution corresponding to about 1 hour 20 minutes, or about 18 revolu-

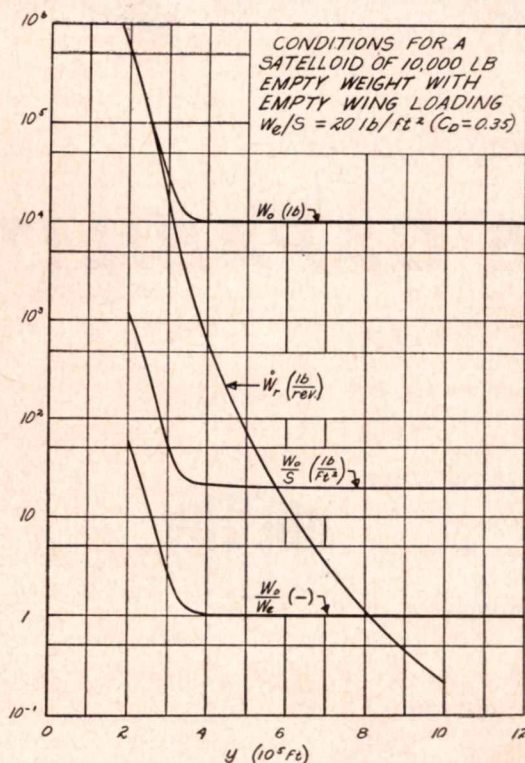


Figure 7



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Satelloid

tions per day, the latter case, at least, is no longer practical.

Aside from the rapidly increasing thrust required with decreasing altitude, the problem of aerodynamic heating also becomes more acute and limits the operating time of the satelloid. Figure 8 shows the variation of the skin temperature, in radiation equilibrium, as function of altitude for a satelloid moving at circular velocity. It is assumed that the satelloid has zero angle of attack, but that its wing and body form a wedge of 20° opening angle, so that the inclination of upper and lower surface with respect to the flow is 10° . The graph indicates that at about 330,000 feet, the maximum temperature for an inconel structure is reached. Protection of the propellant tanks and of the crew compartment is no longer feasible, within the given weight limitations, for more than perhaps one revolution. In practice, the vehicle would probably have to stay at about 350,000 feet altitude if a period of one revolution is considered. For longer cruises, higher altitudes are required.

If the satelloid operates at lower than circular velocity, the flight mechanical conditions become more complicated and the thrust requirements increase rapidly. The reason for this is that the lift force obtainable at these altitudes is very small so that the vehicle, whose apparent weight is no longer zero as for the case of circular velocity, must be supported by thrust.

The capability of the satelloid completing several revolutions around the earth during a given flight operation is not only of scientific and technical interest but also increases the economy of research. It takes a multi-stage booster vehicle and several hundred thousand pounds of propellant to deliver a satelloid with a crew into an orbit. It takes nearly as much to send a hypersonic boost-glide vehicle half around the earth. Yet, while the glider comes down after about an hour flight time, the satellite uses its booster expenditures much more economically by staying up for several revolutions. The value of the satelloid does not lie in the distance covered, but in the greater length of time it stays up for research or crew training.

● ● Interplanetary Applications

The value of the satelloid as an instrument of research in the upper atmosphere and of developing and testing re-entry operations is not restricted to terrestrial applications only. In interplanetary research, satelloids can be used to investigate the upper atmosphere of other planets, such as Mars and Venus, and to prepare for landings by establishing correct re-entry conditions.

In the case of Venus, if at all possible, landing will be extremely difficult, because of heavy turbulence in the atmosphere of this planet. Optical surface observation is also not possible, because of the opacity of the

atmosphere. Thus the exploration of Venus offers a particularly interesting possibility for using a satelloid vehicle, since radar mapping appears to be about the only way by which information about the Venusian topography can be obtained. In order to minimize the ambiguity of radar mapping, low altitude is required, say, about 300,000 feet. Interplanetary space ships, having become temporary satellites of Venus, cannot afford to descend so close to the planet as to enter the outer fringes of its atmosphere. It appears more

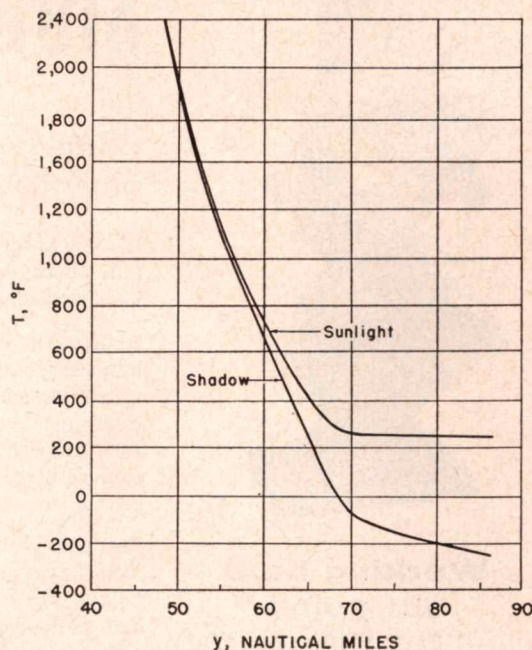


Figure 8—Approximate skin temperature of satelloid.

practical to detach a satelloid which, at the same time would be able to gather information on the Venusian atmosphere proper while conducting a radar reconnaissance mission of Venusian territory.

● ● Conclusion

In summary, it appears desirable to develop low-thrust rocket-powered vehicles, called satelloids, capable of long-duration sustained flight in the extremely rarefied regions of an atmosphere which is too high for a glider and too low for a regular satellite. The reasons pertain to the exploration of the terrestrial atmosphere between 300,000 and 600,000 feet and to the development of a winged vehicle and its operational technique for later transport of persons to and from a satellite at greater distance from the earth. Finally, even after initial difficulties have been overcome, and the exploration of Mars and Venus has become a possibility, satelloids can be highly useful auxiliary vehicles. Thus, the satelloid is not only a stepping stone in the development of manned space flight but also it may accompany man into the depth of interplanetary space.

END

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CHARACTERISTICS AND APPLICATION OF ROCKET PROPELLANTS

Aim of rocket propulsion is to get high performance on the basis of high propellant densities and high combustion efficiency at reasonable cost.

By KURT R. STEHLING
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THE HISTORY of rocket propulsion must include the story of rocket propellants, for surely a large segment of rocket practice is that of testing and developing liquids needed to burn in that unique reaction vessel, the rocket thrust chamber. The story of rocket propulsion is to a large extent a story of the quest for liquids that will yield a higher energy or more thrust for any given configuration or system of rocket propulsion.

The term liquid propellant usually means a liquid or liquids that may be used as the oxygen-supplying liquid, such as nitric acid, a liquid fuel such as gasoline, mixtures of various liquids, and single liquids or "monopropellants" such as ethylene oxide or hydrogen peroxide; the latter liquid may also be used in an auxiliary manner, that is, as a liquid for decomposition in a gas generator, which in turn drives a turbine pump, which is used for pumping the liquids to the rocket thrust chamber of rocket motor.

● ● Choosing a Propellant

An enormous number of liquids have been studied as possible reactants for rocket propulsion. Availability, cost, toxicity and many other chemical and logistic considerations have ruled out many of these liquids, attractive as they may have seemed at first. In the early days of rocket propulsion such substances as ether or the various substituted ethers and unstable compounds of chlorine and various alcohols were tried and discarded because of the undesirable features listed above. Although the propellants used in present rocket propulsion practice have now narrowed down to a small number, most of these have at least one or two undesirable properties—a price that must be paid by the rocket engineer because the very nature of the chemical-combustion process that takes place in a rocket chamber requires liquids that possess a high energy content, that is, liquids that release large amounts of heat upon combustion and that tend to react rather readily either under the influence of a catalyst or heat or pressure or a combination of these.

It is necessary not only to consider the chemical properties of a propellant but also its handling, storage, corrosion, toxicity, bulk-density and other properties. In many examples of modern rocket practice, cost is not a great objection if a mission is achieved by the use of a given propellant, even though it may be an expensive one. However, it is

naturally desirable from both the buyer's and seller's standpoint to reduce costs since the buyer will be more tempted to use a propellant that meets his requirements, even though expensive, in larger quantities, which in turn will result in larger profits for the seller. Many examples of this can be found: for instance, the fuel unsymmetrical dimethyl hydrazine (UDMH) cost about \$20 to \$30 a pound only a few years ago, and today is less than \$2 per pound. Liquid oxygen was an expensive liquid, even as late as the closing days of the last war; however, with modern plant facilities, which may have a production of many tons of oxygen per day, the cost for any missile project using this liquid is a small part of the total cost.

● ● Hazards

No discussion of rocket propellants would be complete without a few lines describing the physical hazards of handling such propellants. These hazards may be divided into two parts:

- 1) **Physiological.** Liquids such as nitric acid and hydrogen peroxide can cause severe burns or blisters and will react with organic substances such as skin. It is therefore necessary for the operator to wear protective clothing, often a considerable nuisance in hot climates or in cramped quarters. The vapors of some liquids, such as aniline or some of the substituted aromatic compounds, may induce cancerous symptoms or conditions, or affect the eyesight or other functions of the human organism. However, in some cases it is necessary for workers to be exposed to the liquids for only a short time.
- 2) **Material Hazards.** These hazards are those that result in explosions, such as the explosive decomposition of hydrogen peroxide when contaminated by certain impurities; corrosion by nitric acid of pipelines, fittings, plumbing and tanks with consequent dangerous seepage of the acid; and the fire hazard resulting from the reactions with many organic material suffered by most oxidizing substances such as liquid oxygen and hydrogen peroxide and to a lesser extent nitric acid. Most fuels have rather low flash points and will burn when exposed to the proper temperature.

The performance of any propellant or given propellants can be computed theoretically, and the actual performance in a rocket chamber can be established experimentally. One of the more useful parameters for judging a propellant's performance is called the characteristic exhaust velocity. Other parameters, which are and have been used, are the effective exhaust velocity, the specific impulse and the ideal exhaust velocity. However, the characteristic exhaust velocity remains a reasonably well understood and powerful parameter. Definition is shown symbolically, Table 1.

Although one would expect that the chemical differences of many liquids suitable as rocket propellants would result in large differences in combustion efficiency, the high thermodynamic limitations that are characteristic of the combustion products limit, or rather minimize the differences among propellants.

TABLE I
CALCULATION OF CHARACTERISTIC EXHAUST VELOCITY

C^* = characteristic exhaust velocity,

C = exhaust jet velocity—difficult to measure experimentally,

C_F = nozzle thrust coefficient—depends on the operating pressures and nozzle geometry

Then $C^* = \frac{C}{C_F}$. C^* can also be computed from the fundamental thermodynamic factors:

$$C^* = \frac{\sqrt{T_c R}}{\sqrt{m \gamma}} \cdot \frac{1}{\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}}$$

Where, $\gamma = \frac{C_p}{C_v}$, or the specific heat ratio,

m = average molecular weight of the rocket chamber gas, and

R = universal gas constant.

Furthermore, the still poorly understood but important physical processes occurring in a rocket chamber further tend to minimize the differences in performance. One of the more important physical processes that acts as a damper is the injection, atomization and vaporization process, which introduces the propellant into the chamber and brings it to the final gaseous phase, and which then exhausts the propellant through the rocket chamber's throat and nozzle to produce the desired thrust. There is possibly as much room for improvement in the design of proper injectors or injection devices for the purpose of increasing the combustion efficiency as there is in selecting propellants of a higher intrinsic energy content. In some cases, it is easier to choose the propellant with the higher energy content since any alteration or change in the physical injection and combustion process is a tedious and often unrewarding enterprise. The following are some of the physical and chemical properties that are desirable in a propellant, and these properties (never met in practice) define the perfect propellant:

- 1) **Low corrosivity.** No reaction with the containing vessels or pipelines or other physical components, which implies, of course, no handling hazard to human operators.
- 2) **Good pumping characteristics.** The liquid should not cavitate easily in any given pumping system and should be liquid at ambient temperatures. It should have, again, no corrosive effect on the sometimes non-metallic seals of pumps and valves.
- 3) **Cooling characteristics.** If the liquid is to cool a rocket engine (not always a necessary requirement), it must have a high thermal conductivity and a high critical temperature, boiling point and specific heat.
- 4) **High density or specific gravity.** (See Figure 1.) A ballistic missile, that is, a missile that has to fight gravity continuously without any assistance such as lift caused by wings, should have a high mass ratio, that is, the largest possible fraction of its total weight should be occupied by propellants. Therefore, the denser a propellant is, the more significant is its contribution to the altitude achieved by any missile. This is true, of course, if the dense liquid has sufficient energy content to enable the vehicle to achieve its mission.
- 5) **Stability.** The propellant should be stable over a wide range of temperatures, that is, it should have a low freezing point and a high boiling point, and should not deteriorate, decompose, or contaminate itself over a period of time.
- 6) **High energy content.** As stated before, a high energy "content" is desirable since this results in a higher characteristic exhaust velocity.
- 7) **Low molecular weight exhaust.** The ideal propellant that meets this requirement is hydrogen, which has the lowest molecular weight of any fuel. Since hydrogen in either liquid or gaseous form is not yet practical, it is desirable to use fuels with a hydrogen content as high as possible.

It is of interest to list the necessary and desirable qualities of a liquid propellant, either oxidizer or fuel, for three hypothetical rocket-propelled vehicles. See Table 2.

Rocket design problems would be eased if only one liquid could be burned in the engine instead of two. A single liquid would have to decompose in the rocket chamber under the influence of high temperature and pressure or both. Electric spark or powder squib ignition is often used; catalytic decomposition (as with hydrogen peroxide) can start the reaction and may be necessary for its continuance. Some monopropellants can be used as fuels or oxidizers. Three examples of monopropellants are:

1) **Nitromethane.** This pale yellow liquid has a density of 1.12, a flash point of -20°C and a boiling point of 101.2°C . It burns quietly when unconfined. It will deteriorate under certain conditions of tempera-

ture and pressure. Explosions resulted during early rocket engine firing tests with this material. A detonation wave would travel upstream from the rocket thrust chamber into the pipelines and explode the nitromethane. Detonation traps and propellant additives have reduced this problem.

2) Hydrogen Peroxide (85 percent, and greater concentration.). This substance is an old favorite, having been used by the Germans in World War II for the Me 163 and *Natter* rocket fighters. (Here it was used as the oxidizer with hydrazine hydrate as the fuel.) The 90 percent liquid has a boiling point of 286°F and a flash point of 12.6°F, which can be reduced by additives. See Reference 2. It is easily decomposed by various organic and inorganic material. A widely used catalyst has been calcium permanganate. Although peroxide's widest use has been as a steam generating material for turbine-pump gas generators, it has good potentialities as a rocket engine monopropellant or oxidizer because of its high density, ready availability and simple usage. If peroxide's

chemical reactivity (with many organic materials) and physical (high freezing point) properties can be solved, perhaps by additives, then it might become a much more widely used propellant.

3) Ethylene Oxide. This colorless liquid, boiling at 10°C, has possibilities for rocket use but will require further research and testing in order to establish adequate performance.

● ● Oxidizers

The development of an oxidizing liquid which would have the relatively innocuous properties of, say, gasoline has not yet been accomplished. The very nature of an oxidizer demands that it be chemically vigorous if it is to fulfill its oxidizing function efficiently. The following are some oxidizers which have an actual or potential use:

Liquid Oxygen (LOX). This substance has been a favorite oxidizer for many years. Even the various rocket societies before World War II found LOX to be a convenient oxidizer despite its handling properties

TABLE 2—CHARACTERISTICS OF PROPELLANTS FOR SPECIFIC APPLICATIONS

MANNED ROCKET RESEARCH AIRCRAFT — TURBO-PUMP FED
(Limited Production)

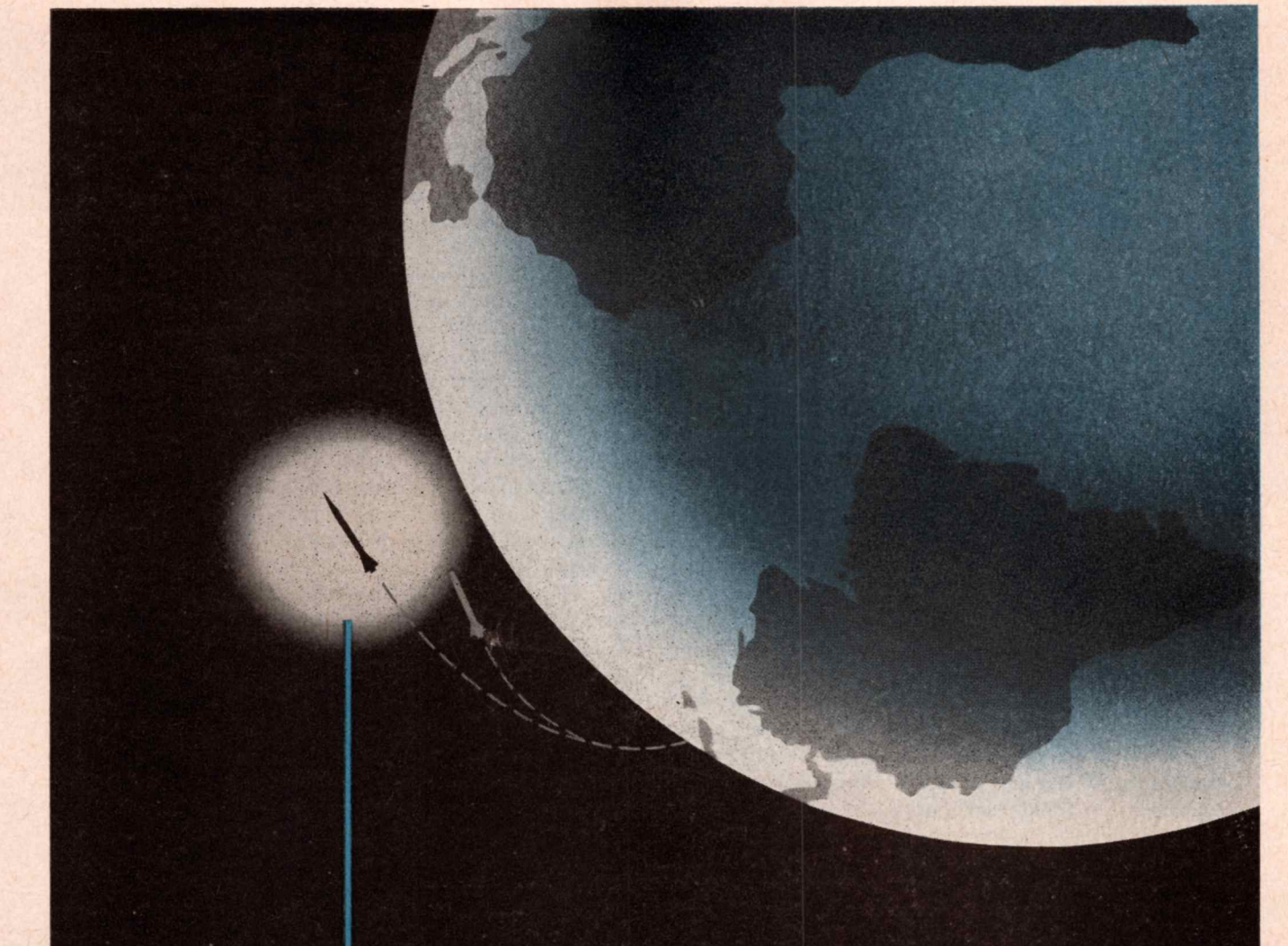
Desirable	Necessary	Tolerable
Non-Toxic	Safe handling	Some toxicity
High density	Better than "average" density	Some handling hazard all right, but aggravates the servicing problem
Non-hypergolic	Good pumping characteristics	Hypergolicity could be tolerated but handling hazard must be recognized
High specific impulse	Good storageability (Research aircraft often have a long "hold" time)	High cost/lb. and low availability
Liquid at ambient temperatures	Low corrosivity	Medium or "average" specific impulse
	Ability to cool the engine	Liquid gases, for example, oxygen, are widely used because the designer has no other choice if he wants high performance

LONG-RANGE UNMANNED MISSILE — TURBO-PUMP ROCKET ENGINE
(Production Type)

Desirable	Necessary	Tolerable
Non-toxic	High Density (to achieve high mass-ratio)	Fairly toxic (The surrounding area and crew must be considered. The area would most likely be isolated. A potentially dangerous substance could be handled safely by a well-trained crew)
Safe handling	Good pumping properties	A highly corrosive and chemically active propellant can be used, but it increases handling hazard
Hypergolicity (eases initial ignition problem or re-ignition, if necessary)	High specific impulse	Liquid gases are often a necessary compromise
Low cost/lb	Good history of combustion stability, and good cooling characteristics	
Ready availability in large quantities		
Good storageability		
Low corrosivity		
Liquid at ambient temperatures		

SHORT-RANGE HIGH-ALTITUDE OR ANTI-AIRCRAFT MISSILE — PRESSURE FED
(Production Type)

Desirable	Necessary	Tolerable
High density	Low toxicity (Storage of these propellants is often near inhabited areas or crew quarters)	Low handling hazard
Low cost/lb	Safe handling	High vapor pressure
Ready availability	Better than "average" density	Some corrosion all right if quality control of propellant is maintained
	Hypergolicity eliminates ignition problem, although hazard is increased	Propellant may not need to be a good coolant. Uncooled engine could be used
	Good storageability	
	High specific impulse, especially for high-altitude vehicle	
	Low corrosivity	
	Liquid at ambient temperatures	

An illustration of a satellite launch against a black background. A large, detailed Earth is in the upper right. A satellite is shown in orbit, with a dashed line indicating its path. A solid blue line extends from the bottom left towards the satellite, representing a signal or trajectory.

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(it is a liquid at -297°F) and difficult procurement in non-industrial areas. It has been and is being widely used in rocket research aircraft and such applications as the first stage *Vanguard* launching vehicle.

Nitric Acid (fuming). Nitric acid (and the oxides of nitrogen) have been widely reported in the unclassified literature (Reference 3) as propellant oxidizers. While nitric acid (white and red fuming) does not yield as high an efficiency as oxygen with most fuels, it is cheaper and more easily storable than LOX. However, the acid introduces severe problems of handling since it is very corrosive.

Ozone. Although the specific impulse of ozone and ozone-oxygen mixtures is not much better than that of liquid oxygen, the density ratio or amount of useful oxidizer per unit volume is superior. If liquid ozone could be produced in quantity, it would considerably improve the performance of vehicles peculiarly dependent on mass ratio. While LOX can be produced by a cyclic process of compression, expansion and "distillation" of air, ozone must be produced from very pure gaseous oxygen which is passed through an electrical discharge or corona apparatus which dissociates the O_2 molecule and then permits recombination as O_3 .

This apparatus must inevitably be more bulky and expensive than a LOX generator. Furthermore, ozone or ozone-oxygen mixtures are rather sensitive to small quantities of organic impurities; this could result in explosions or rapid decomposition.

Nevertheless, if a thorough program of thrust chamber and materials handling testing were undertaken in the next few years, this material would undoubtedly find an important place in the oxidizer usage for rocket propelled vehicles.

● ● Fuels

Hydrocarbons (other than alcohols). The petroleum derivatives such as "jet fuel," kerosene and gasoline are tried and proven fuels and are widely used. Their combustion efficiencies with most oxidizers are good. One problem associated with hydrocarbon fuels is the lack of rigorous standardization of a specification, since a derivative such as gasoline is a heterogeneous substance, that is, a blend of various aromatic and aliphatic hydrocarbons.

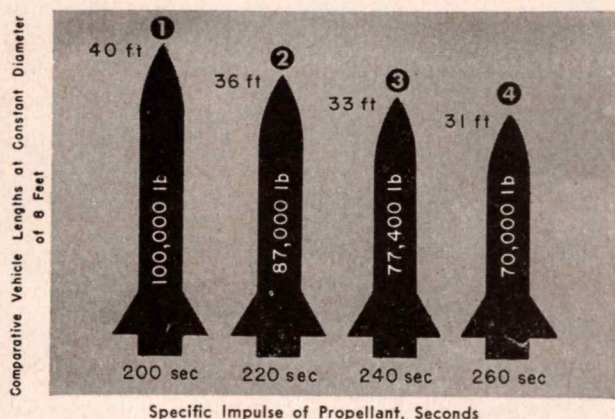


Figure 1—Rocket vehicle size decreases with an increase in specific impulse. (Constant payload, design altitude and mass ratio.)

Hydrazines and Ammonia. The ammonia or ammonia-like fuels have a larger fraction of their molecular weight as hydrogen than the hydrocarbons, which results in higher exhaust velocities, yet their densities are usually similar or better than those of the hydrocarbons. A good example is unsymmetrical dimethyl hydrazine (UDMH). This substance has a density of 0.784, a freezing point of 58°C . It (like mono-methyl or anhydrous hydrazine) is hypergolic with nitric acid. Its good density, ready ignition and high performance make it an attractive fuel. Indeed, it has been chosen for stage II of the *Vanguard* satellite because of these qualities.

Alcohols. The alcohols, especially ethyl alcohol, like LOX, have had a long and honorable history of rocket propellant usage. The higher densities, lower cost and somewhat greater combustion efficiencies of the hydrocarbons have tended to place ethyl alcohol in a lesser role in modern missile practice.

Hydrogen. This gas yields the highest combustion efficiency of any fuel. However, its very low density, even as a liquid, results in an unfavorable propellant loading factor (or mass ratio) for missiles of reasonable size. Furthermore, hydrogen is difficult to liquify and store as a liquid in rocket propellant tanks.

● ● The Future

The inherent thermodynamic limitations of chemical propellants limit the gains in combustion efficiency which may be made in the next few years.

Some progress will be made in improving the physical preparation of the propellants for burning, that is, the processes of injection, atomization, mixing and evaporation.

The search will go on for an oxidizer that is safe and simple to handle, easily available and thermally efficient. It should be stable over a wide ambient atmospheric temperature and be storable without the use of special equipment.

Some progress may be made in the development of organo-metallic compounds. See Reference 4. Boron and lithium are two metals which have been combined with hydrogen to form compounds such as pentaborane or lithium hydride. These compounds burn with an intense heat and their use in certain combustion processes could materially improve the efficiency of the combustion. The hydrazines, especially dimethyl hydrazine, warrant further investigation and development. The use of unsymmetrical dimethyl hydrazine in *Vanguard* should increase the prestige of this fuel.

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The author thanks William Escher of NRL for contributing some of the data for this article.



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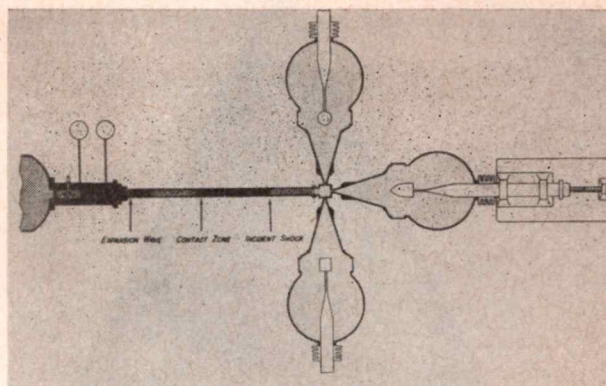
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MARTIN

Figure 1—Schematic view of hypersonic shock tunnel, consisting of a driver tube, a driven tube and a set of nozzles.

Laboratory tests using gas shock tunnels and mass accelerators can yield valuable data for research in the ballistic range of velocities.

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Planning for HYPERSONIC WIND TUNNELS

FOR EXPERIMENTAL STUDIES in the subsonic, transonic and supersonic regimes, the most useful and common experimental facilities are wind tunnels, which may either be continuous-operating or intermittent-operating type. In either case, the model is stationary and the air, heated to a proper temperature, is expanded in a nozzle and flows around the model at a certain Mach number and density. It may be noted that to date the gases in wind tunnels are heated to prevent condensation rather than to match temperatures for flight similitude. If air at room temperature, for example, were expanded in a nozzle, the oxygen and nitrogen would start to liquefy roughly at a Mach number of four. At higher Mach numbers the size, cost and complexity of such facilities increase rapidly. For example, a Mach 10 tunnel of one-foot diameter test section operating at 1000 psi and 1000°F reservoir conditions would require more than 3000 hp to push the air through a $\frac{3}{8}$ -inch diameter throat, and the heating load would be of the order of one megawatt.

With intermittent operating wind tunnels it is possible to reach much higher Mach numbers—of the order of 30—for a period of a few seconds or minutes, by using gases other than air, such as helium, which can be stored in a tank under pressure and has a very low condensation point. But the important new problems such as dissociation, thermal radiation and mass ablation become serious above 3000°F; and in the present state of development of wind tunnels, engineers are beginning to tackle this new and difficult problem area—namely, design of hypersonic wind tunnels operating at reservoir temperatures sufficiently high to simulate important real gas effects.

Among a number of other techniques, such as combustion tunnels, shaped charge techniques and solar furnaces, which have been tried in the past few years to produce realistic phenomena associated with hypersonic flows, the facilities that currently seem to hold the most promise for useful, meaningful, laboratory type investigations (excluding the presently uneconomical proposition of free-flight testing) are the shock

tubes, shock tunnels and mass accelerators. With any of these facilities it is quite feasible to attain perfect gas temperatures of over 20,000°K, but this is accomplished by reducing the duration of the tests sufficiently to prevent damage to the facility. With such facilities the duration of each run is of the order of a millisecond, and to get time-resolved information about the highly transient phenomena, microsecond instrumentation must be used throughout. The important developments in instrumentation which have taken place in very recent years make the future look promising in this direction. In this connection one might mention sub-microsecond temperature and pressure gages, motion picture cameras capable of taking several million pictures per second, and great advances being made in telemetering and recording apparatus.

● ● Shock Tunnels

In the shock tunnel the model is stationary, and the test gas, which is rapidly heated by shock waves to the desired temperature, is made to flow at the desired Mach number and density around the model. Although minor variations on the basic scheme can be made, a typical aerodynamic cycle for the shock tunnel is shown in Figure 1.

The tunnel itself consists mainly of a driver tube, a driven tube and a set of nozzles. Initially, conditions are at room temperature with a main diaphragm separating the driver tube end and the driven tube, and perhaps a weak second diaphragm separating the driven tube from the nozzles, which are usually evacuated to as high a vacuum as feasible to minimize flow starting losses.

Following a sudden release of energy in the driver tube (such as the explosion of a combustible mixture of the gases) the main diaphragm is broken and a strong shock propagates down the driven tube, heating and compressing the gas behind it. The shock wave hits the end of the tube and is reflected, leaving a reservoir of gas behind it which is further heated and compressed to perfect gas temperatures of the order

of 20,000°K and several thousands pounds pressure. The reservoir gas is then expanded in one or more nozzles properly designed to simulate free flight temperatures, Mach numbers and densities at the test section, while cold expansion waves begin to propagate downstream to quench the process and bring final conditions down to safe levels. In this manner free flight conditions of the order of Mach 20 can be matched at fairly reasonable altitudes.

The shock tunnel is of great interest not only for studying hypersonic flow field problems but also for studying properties of gases at extremely high temperatures such as radiation, emissivity, electron density, signal propagation through ionized gases, and relaxation times and transient phenomena behind strong shocks; and possibly magnetohydrodynamic problems associated with highly ionized gases flowing at high speeds.

Information obtained from mass accelerators, Fig-

jectile, and the mass of the gas itself. Hence the heavier the gas, the less energy is available for the projectile; and in fact in any case there is a limiting velocity that corresponds to the condition where the available energy is just sufficient to accelerate the gas to a certain speed. Hence no projectile can, in practice, be pushed anywhere near that speed.

With nearly all chemical processes of energy release such as the explosion of nitrocellulose gun powder or combustion of hydrogen-oxygen mixtures, the flame temperature is less than 0.4 ev and the corresponding limiting velocity is around 25,000 ft/sec. In practice, in any real system, it is found to be extremely difficult to get 15,000 ft/sec, which is far short of orbiting velocity, for instance.

• • Electrical Energy

The use of electrical energy would appear to be the next logical step in the development of the gas gun.

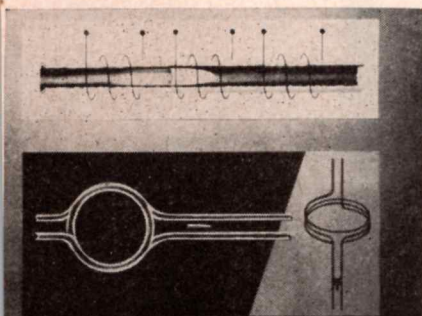


Figure 2—Electromagnetic mass accelerator (upper), and d-c mass accelerator.

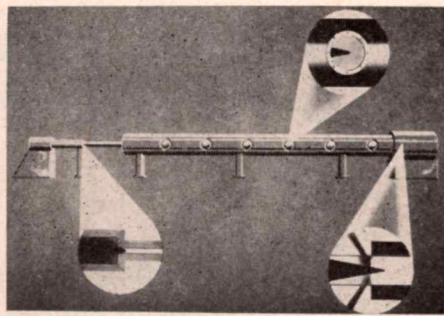


Figure 3—Hypersonic gun tunnel. Expanding gas pushes the projectile out of a launcher into a range where information is obtained by high speed optical and electronic systems.

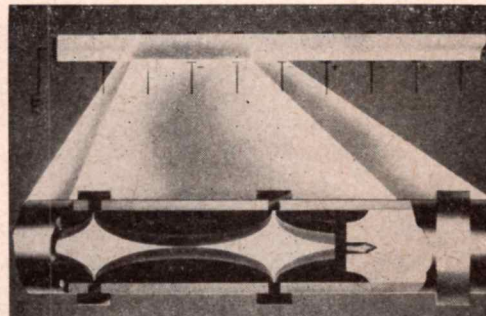


Figure 4—Electrical arc mass accelerator.

ure 2, complement rather than duplicate that obtained from shock tunnels. Mass accelerators are used to shoot models at high velocities into a ballistic range where the density is adjusted to simulate desired Reynolds numbers or interaction properties. As the model flies in the range, it is studied by high-speed optical and electronic equipment. Mass accelerators are particularly useful on problems such as those dealing with stability and control, over-all forces, mechanism of mass ablation, and impact phenomena. Future possibilities may lie in the area of meteor phenomena, and super-aerodynamics problems (at high altitudes) such as those concerned with rarefied gases, free molecular flow, slip flow.

The common technique of accelerating masses in ballistic facilities is to cause rapid heating and expansion of a gas behind the projectile by the sudden release of an amount of energy into that gas. The expanding gas pushes the projectile out of a launcher into a range where information is obtained from the projectile by high-speed optical and electronic systems and by telemetry, Figure 3.

The energy released to the gas, which is stored as potential and thermal energy in the gas, is converted into kinetic energy used up in accelerating the pro-

The equilibrium gas temperature for a high current electrical arc, for example, is accepted as 2 ev, and if such energy is poured into helium, the corresponding limiting velocity would be 60,000 ft/sec. Moreover, by distributing electrodes along the barrel and releasing energy behind the projectile in a calculable manner, Figure 4, it should be possible to cancel the rapid decay of pressure that takes place behind the projectile in all the usual types of guns, and hence produce faster acceleration.

Electrical energy can be used in other forms to accelerate masses. For example, a linear accelerator can be used by setting up a field of rapidly moving electromagnetic waves to carry a metallic object by induction, as was tried as early as 1937 at the University of Utah. Or else the tremendous radial bursting forces set up in a coil upon the sudden discharge of large currents through the coil can be used to push a projectile by making the projectile form part of the coil but free to move in the radial direction. This idea has been given considerable thought during the past few decades. Although there are no apparent limitations to speeds obtainable by these techniques, there are still a number of practical problems to be solved before they can be useful engineering tools. END

LOGISTICS FOR LIQUEFIED GASES

**In commercial supply of liquefied gases
value is measured in terms of dollars.
Yardstick is proposed for the military to
standardize logistics for liquefied gases.**

IN THE TWELFTH CENTURY, when Genghis Khan overran China and part of Russia, his secret weapon resided in his cavalry, which was able to cover great distances and still arrive at the battlefield rested and well fed. For years it was not known how he nourished his troops without their taking the time and energy to live off the land. The answer was simple: they were fed by tapping the blood of their horses. Genghis Kahn brought his full military strength to bear at the zero hour and at the same time was untroubled by the basic problem in logistics—depletion of his resources.

Through the years the implementation of military planning may not have changed much in kind, but it

is certainly much more complex in all its interrelated technological detail. Innovations come along at such an accelerated rate that the practice of logistics is not really comparable with pure text book logistics about which all of us know something. It is, however, vitally important in order to communicate, interpret and properly weigh both the military requirements and the economic factors that the underlying criteria be defined just as clearly as possible, and then in all probability a better solution will result.

As applied to the support of missiles using liquefied gases in their propellant systems, many unique problems associated with handling large volumes need to be worked out. Some of these problems are brought

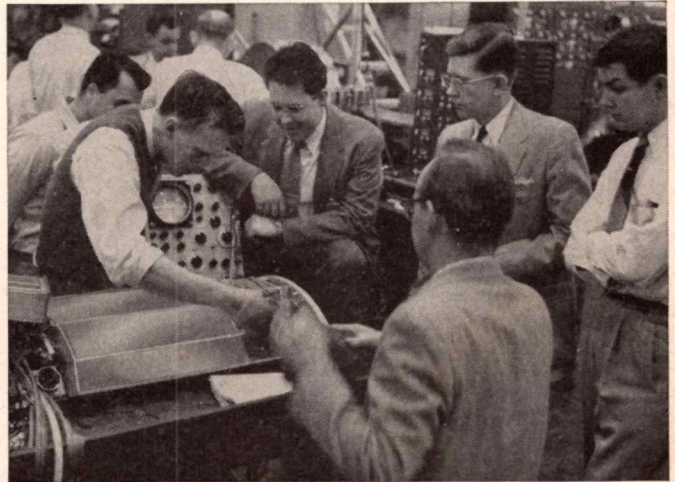
Roger Warner, Jr.
Vice President and Chief Engineer
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Bendix GUIDED MISSILES

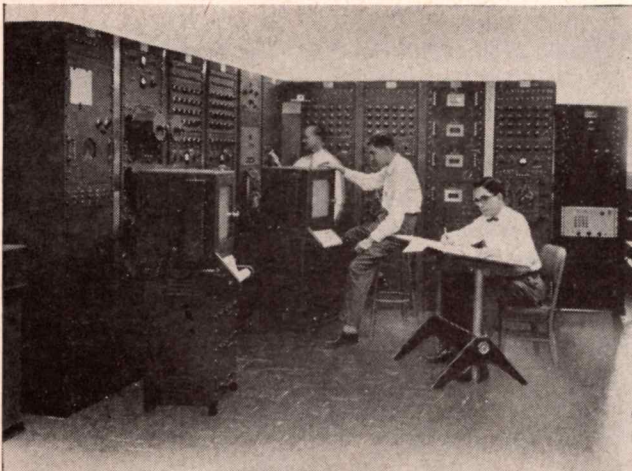
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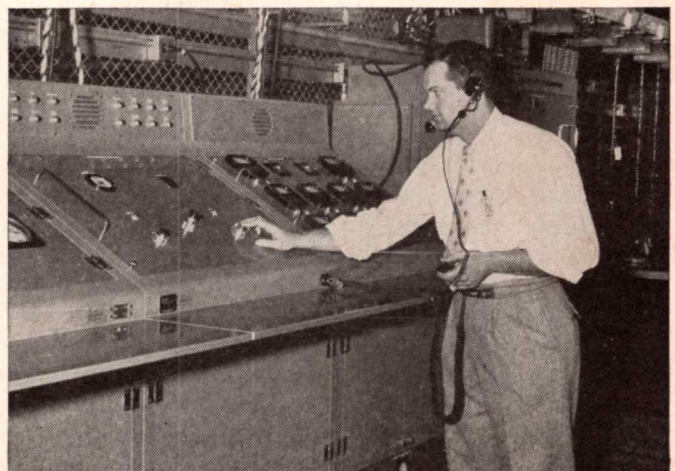
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about because of the unique properties of gases liquefied and stored at extremely low temperatures. The full-scale need in the missile development programs has outstripped the capacity of existing facilities and the capability to supply will need to be scaled up so that an increasing number of people will be brought in to implement this new facet of the defense machine.

To put the problem another way, one sees that if logistics is not attended to, then gaps in handling machinery will certainly result. This will lead to ineffective distribution of the gases, creating acute shortages in some places owing to depletion in handling and storing. Ineffective logistic support also ties down the mobility and flexibility of the limited resources of manpower and equipment. For example, a tank trailer designed for storage with low losses would in all probability have a relatively low tank capacity and therefore would be most useful at locations far removed from liquefaction facilities where the value of the gases was much greater than at the liquefaction base. However, in areas where the gas has low value it would be proper to consider a reduction of the insulation in order to increase the capacity to be transported. Losses of gases due to heat leaking into the storage tank, cooling down in transfer operations, temperature and volume increases with increased pressure, and sloshing during transportation are factors contributing to the depletion of the propellant in the supply line, and these contribute very significantly to the value of the gas at the point of use.

● ● Common Denominator

In order to arrive at the most favorable combination of material and supply, it is necessary to attach a value to the product at the point of use. This value is in part determined for liquefied gases by the accumulation of losses, length of time in transit, number of transfers from container to container, and maybe the age of the material from the time it was liquefied.

In the commercial supply of liquefied gases, an understandable and obvious value of the product at the point of use can be given in terms of dollars. However, the value in dollars does not seem to be the whole answer to the military logistics problem—here the value may be quite different. Requirements are based largely on a full and flowing pipeline so that, even with part of the line damaged, there will still be some continuing flow. The military commander in the field might measure support available to him in terms of days of fire power. For example, a command might be allocated a specified amount of support credit with which to accomplish his mission.

He is told, "Use it any way you want, just so you get the job done."

Here, he must evaluate how to achieve so many units of fire with greatest effectiveness. While he may not use dollars, he will use some digits and analogues which are the military equivalent of dollars.

Yet this military measuring stick is a nebulous one. The military man's primary interest is how many units of military performance he has at his command.

The maximum number of such units per dollars of effort is his goal. One could say that he wants the maximum accomplishment for the minimum cost.

Once a yardstick such as this has been established, it is possible for industry to interpret the necessary amount of care to be exercised in preserving and transporting the military products.

To arrive at maximum accomplishment at minimum cost, industry and the military must go far beyond the question of what equipment is to be designed. They face a broader question:

What must the equipment accomplish to meet a military objective at the cheapest possible cost?

On this basis, it might be useful to ask whether it is advisable to conserve liquefied gases in transit or whether it is more effective to deal with larger volumes of such gases and expect losses. Where the gas is inexpensive, it may be better to take the latter course. Oxygen, for example, has very little worth per gallon as a liquefier. On the other hand, some of the lower boiling point gases, such as hydrogen and helium, are at the present liquefied at a cost many times that of oxygen. Thus, hydrogen and helium have an initial value that might surely make it prudent to protect from loss as much as possible.

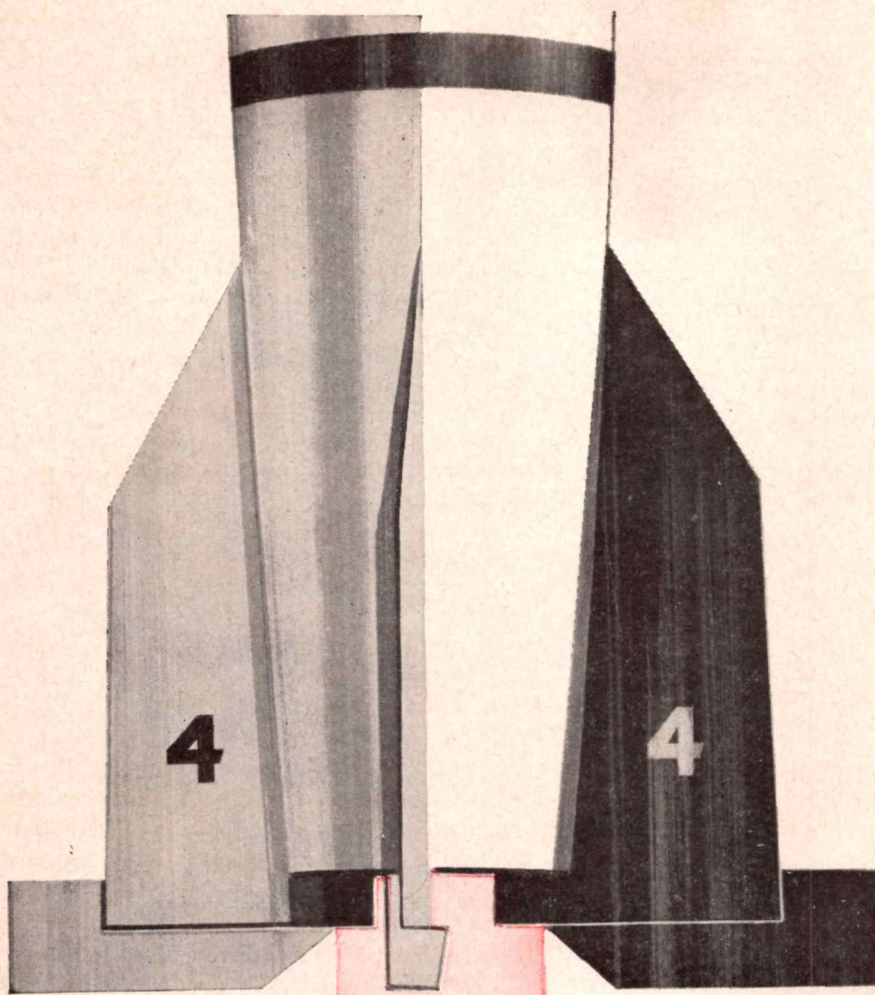
Other factors that bear upon the logistics problem of liquefied gases are found in establishing or meeting established standards for safe transport over civilian highways, availability of men and equipment to handle them, together with the possibility of standardizing such equipment. This latter factor is a tremendously important one because it affects flexibility and utility, spare parts needed and manpower training.

Many of the above factors are dependent on the distance the liquefied gas is to be moved. If the distance is long, then which is the better method—intermediate storage or direct transfer to destination? Is it best to put a lot of money into conservation to maintain the liquefied gas to as close to a no-loss level as possible, or will such precaution increase the equipment complication and also result in lower available capacity? These and a host of other questions must be answered before a standardized and effective large scale logistics system for liquefied gases can be achieved. Industrial support to the military in terms of equipment for gases can minimize the cost of transporting such gases; and it is up to the military to get maximum accomplishment out of such equipment at the point of use.

It is suggested that all of us bitten with this problem attempt to sharpen the criteria indicated by the military requirements for liquefied gas equipment and transport, and value at the point of use is the yardstick proposed. With such improved interpretation the military can be assured of maximum accomplishment for minimum cost.

The logistic requirements need to be integrated, sharpened and interpreted into complete logistic equations. Thus equipment can be conceived, built and tried out in order that the most attractive support equations evolve.

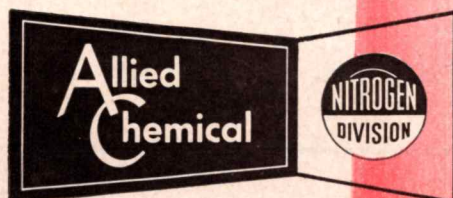
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LOOKING BACK on 25 years of rocket history, one will be inclined to agree that most of the things pronounced today as technical facts or serious projects would at that time have appeared to most engineers and scientists as hair-raising, phantastic delusions. This experience should be mentioned before discussing the flight mechanics of a presently hypothetical rocket system, the exhaust mass of which attains the highest velocity possible, namely the velocity of light; that is, the system of the *photon* rocket or *neutrino* rocket.

Before attacking the difficult, but in no way hopeless, technological problems involved in photonic propulsion, one is inclined to ask what is to be expected from such a new technical instrument in the event of its successful completion. In this, I do not wish to include extraneous fields of application of the photon rocket, for example, the consideration that such powerful photonic jets may possibly constitute an effective defense against the so-called ultimate weapons—the intercontinental ballistic missiles—by directing these jets as all-melting searchlights against flying objects. Rather, I wish to limit this consideration to the pure application of such powerplants in space vehicles and, furthermore, to purely flight mechanical phenomena. The flight mechanics of the photon rocket alone lead to such profound conclusions, in which technology starts to show almost metaphysical aspects that its special treatment can be considered justified.

● ● Photonic Velocity Concept

A photonic rocket powerplant with high or complete conversion of matter into radiation is assumed

as being available; the fuel masses carried in the photonic vehicle are converted almost completely, or entirely, into quanta without proper-mass (photons, neutrinos, anti-neutrinos and so forth), which are emitted in a pre-selected direction at the velocity of light. Further, it is assumed that such a photonic space craft moves in gravity-free and resistance-free space in one straight direction.

At first, the known classical basic equation of rockets relative to a coordinate system fixed in the vehicle, the so-called “Eigen-system” (proper-system) is applied. This equation gives a relation between the ratio (m_e/m_{e0}) of instantaneous proper mass to initial proper mass, and the ratio v_e/c , obtained proper flight velocity to exhaust velocity, the latter in this case being equal to the velocity of light.

$$v_e/c = -\ln(m_e/m_{e0}) \quad (1)$$

We use the meaningless word “proper-velocity” for the convenient parameter v_e , to indicate that v_e is no real velocity in the physical sense.

From Equation 1, it immediately follows that for $(m_e/m_{e0}) = e^{-1}$, the proper flight velocity v_e becomes equal to the velocity of light c ; and for $(m_e/m_{e0}) = e^{-10}$, it becomes equal to ten times the velocity of light and so on.

This conclusion makes one somewhat thoughtful, and one wonders about the nature of this strange proper velocity v_e that arbitrarily exceeds the velocity of light.

The crew of the vehicle therefore will try to measure velocity in a different way. Assume that the crew is equipped with conventional chronometers and thus

In this exclusive Aero Digest article, the author deals with the ultimate not only of space travel, but also of humanity itself; and in the case of photonic rockets, our technology, natural science, philosophy and even mythology and religion begin to flow into one common channel.

Flight Mechanics of

EUGEN SÄNGER

Director, Research Institute for Physics of Jet Propulsion
Stuttgart, Germany

PHOTON ROCKETS

are able to measure their own proper time, for example, starting with the beginning of the propulsive process,

$$t_e \quad (2)$$

Furthermore, assume that they are equipped with conventional accelerometers, for example, a small mass suspended on a spring; thus, they also would be able to measure their own proper acceleration

$$b_e \quad (3)$$

With these two values, the crew will start their calculation and first determine their proper flight velocity in the conventional way as,

$$v_e = \int_0^{t_e} b_e dt_e \quad (4)$$

The result of this calculation will be in fine agreement with the calculation according to Equation 1 in determining the proper velocity v_e obtained through the propulsive process. Again they will find, after appropriate time, that v_e exceeds the velocity of light.

The crew may evaluate their measurements inside the craft still further and calculate a proper distance s_e traveled, according to

$$s_e = \int_0^{t_e} \int_0^{t_e} b_e dt_e dt_e = \int_0^{t_e} v_e dt_e \quad (5)$$

This is all in agreement. The crew does not have to be suspicious of their instrument measurements, as the men may check the readings of their chronometers, for example, against their own pulse rate. They will especially sense physiologically the proper acceleration. They may even try to regulate their rocket propulsion in such a way as to maintain constant proper acceleration b_e , possibly even at the value of $b_e = 10 \text{ m/sec}^2$ most favored by the crew from their terrestrial experience.

For the case of $b_e = \text{const.}$, the derived determination of proper velocity and proper distance are especially easily determined as

$$v_e = b_e t_e \quad (6)$$

$$s_e = b_e (t_e^2/2) = v_e^2/2b_e \quad (7)$$

with the aid of the classical relations for uniformly accelerated motion.

● ● Relativity of Time and Distance

Such a flight of course will also be carefully observed and measured from the Earth with the aid of numerous instruments. It is possible that the measurements made at certain instances of time, for example, after a certain fuel consumption, which is characterized by the pertaining (m_e/m_{e0}) , will be communicated between observer on the Earth and crew of the space craft.

With this, considerable discrepancies between the velocity of the craft v , the acceleration of the craft b , the running time t , and the distance s traveled, all measured by the observer on the Earth, and the respec-

tive measurements of v_e , b_e , t_e and s_e by the crew will eventually appear.

After a certain number of measurements, it will be learned that there exist the known relativistic equations, valid for arbitrary proper accelerations,

$$v/c = [1 - (m_e/m_{e0})]^2 / [1 + (m_e/m_{e0})]^2 \quad (1a)$$

$$= \tanh (v_e/c) \quad (4a)$$

$$(dt/dt_e) = \cosh (v_e/c) \quad (2a)$$

$$(b/b_e) = \cosh^{-2} (v_e/c) \quad (3a)$$

$$(ds/ds_e) = [\sinh (v_e/c)] / (v_e/c) \quad (5a)$$

between the respective groups of measurements of the observer on the Earth and those of the crew. In these simple relations there lies the entire mystery of the crew's experiences in the photonic space craft, gaining its full emphasis only for such high flight velocities v that approach the electromagnetic signal velocity c , where thus every means of communication between observer on the Earth and crew is cut off and thus a direct comparison of respective measurements ceases to be possible.

It seems that in gravity-free and resistance-free space almost no limits on the constructional ratio (m_e/m_{e0}) between terminal and initial proper mass of the vehicle are imposed, especially if the fuel-matter to be converted into radiation are themselves solid and self-supporting bodies being consumed only in the course of years.

Therefore, at first the ratio (m_e/m_{e0}) is presented in a large range in Figure 1, plotted against the thereby obtainable ratios of proper velocity v_e and the relative velocity v , respectively, to the velocity of light c with the aid of Equations 1 and 1a respectively.

These ratios, namely v_e/c and v/c , are designated "Einstein-numbers" of space flight, in analogy to the "Mach numbers" of atmospheric flight. Whereas the proper Einstein-number may have values arbitrarily larger than 1, the relative Einstein number naturally approaches the value of 1 without ever reaching it.

Connected with this is the fact that the acceleration of the vehicle b , as observed from the Earth, soon decreases rapidly below the proper acceleration b_e experienced by the crew in the space craft. While with constant proper acceleration b_e , for example, the proper velocity v_e proportionally increases with the proper time t_e , it appears to the observer on Earth that the relative velocity v rarely increases, as it asymptotically approaches optic velocity c .

Even stranger are the ratios of times and distances, if those from the point of view of the terrestrial observer and those from the crew are compared.

Plotting the ratio dt/dt_e of observer time to crew time, according to Equation 2a in Figure 1, we see that, for example, at $v_e/c = 18$ the observer experiences a lapse of one year while the crew lives through one second.

At $v_e/c = 32$, one million years would pass on the Earth, this interval appearing to the crew as one second. For the hypothetical population on a photon, for which $v_e/c = \infty$ and thus $v/c = 1$, the thing we terrestrials call time would be static, that is, it would not exist at all. Such beings would live outside our

world with respect to time, their course of time would have no relation whatsoever with ours.

Assuming, for example, a photon would be sent from the Earth to a star ten light years distant and be reflected there so as to return to Earth, this photon would arrive here after 20 years. However, for a passenger on this photon no time would elapse during this process. He would gain the impression to have moved through this journey with infinitely high velocity. The crew of the photonic space vehicle will never fully experience this strange state of the inhabitants of the photon. However, it approaches this state for high proper Einstein numbers of the flight quite closely.

● ● Measurements by Crew

In the study of the distances ds and ds_e , there appears a complication insofar as we have to consider still a third measured distance ds'_e . The determination of the kinematic proper quantities of the crew, t_e and b_e , and the proper quantities v_e and s_e derived therefrom, is made without any reference to the surroundings of the vehicle, hence without observation of events outside the vehicle. The measurement of the relative quantities t , b , v and s from the Earth to the vehicle is made with the aid of conventional, for example, astronomical, instruments.

Assuming that the crew inside the space craft also has such instruments available and is able to make appropriate measurements of t'_e , b'_e , v'_e and c'_e from the vehicle to the Earth, we see that the results of these measurements naturally are of interest in relation to the relative and proper quantities treated up to now.

It is immediately apparent that the time t'_e thus determined is nothing but the proper time t_e ; hence $t'_e = t_e$, and the velocity v'_e measured from the vehicle to the Earth and the relative acceleration b'_e must be identical with the respective relative magnitudes v

and b measured in the opposite direction; hence $v'_e = v$ and $b'_e = b$, as it is of no consequence to those measurements whether the vehicle or the Earth is considered at rest and the other respective object moving.

It is somewhat different, if the length of a certain path, lying in the trajectory and being at rest relative to the Earth, for example, the distance S of the Earth from the destination of the trip, is measured from the vehicle. Every element ds of this path then moves relative to the vehicle at the velocity v and thus is subject to the relativistic dilation of length,

$$\begin{aligned} ds/ds'_e &= [1 - (v^2/c^2)]^{-1/2} \\ &= \cosh (v_e/c) = (dt/dt_e) \end{aligned} \quad (8)$$

Measured from the Earth, this distance at rest with respect to the Earth therefore appears longer than if measured from the vehicle, and in the same ratio as the two time measurements from these respective points of observation.

Plotting this ratio ds/ds'_e of the distances measured by the terrestrial observer to those measured by the crew in the vehicle, according to Equation 8 in Figure 1, we see that the graph coincides with the plot for dt/dt_e and shows that, for example, at $v_e/c = 19$ an astronomical distance such as that between the Earth and our Sun appears to the crew only one kilometer long, and that for $v_e/c = 32$ the distance of our Sun from the nearest neighboring sun, Alpha Centauri, which is measured by terrestrial astronomers as $4\frac{1}{3}$ light years, appears to the crew as also only one kilometer long.

These distances are covered, at the proper velocities mentioned, in approximately $0.317 \cdot 10^{-5}$ and $5.36 \cdot 10^{-5}$ proper seconds, respectively.

To our hypothetical inhabitants of a photon, moving with this light quantum at optic velocity relative to us, all lengths of our world appear contracted to zero. Our world would appear to them consisting only of

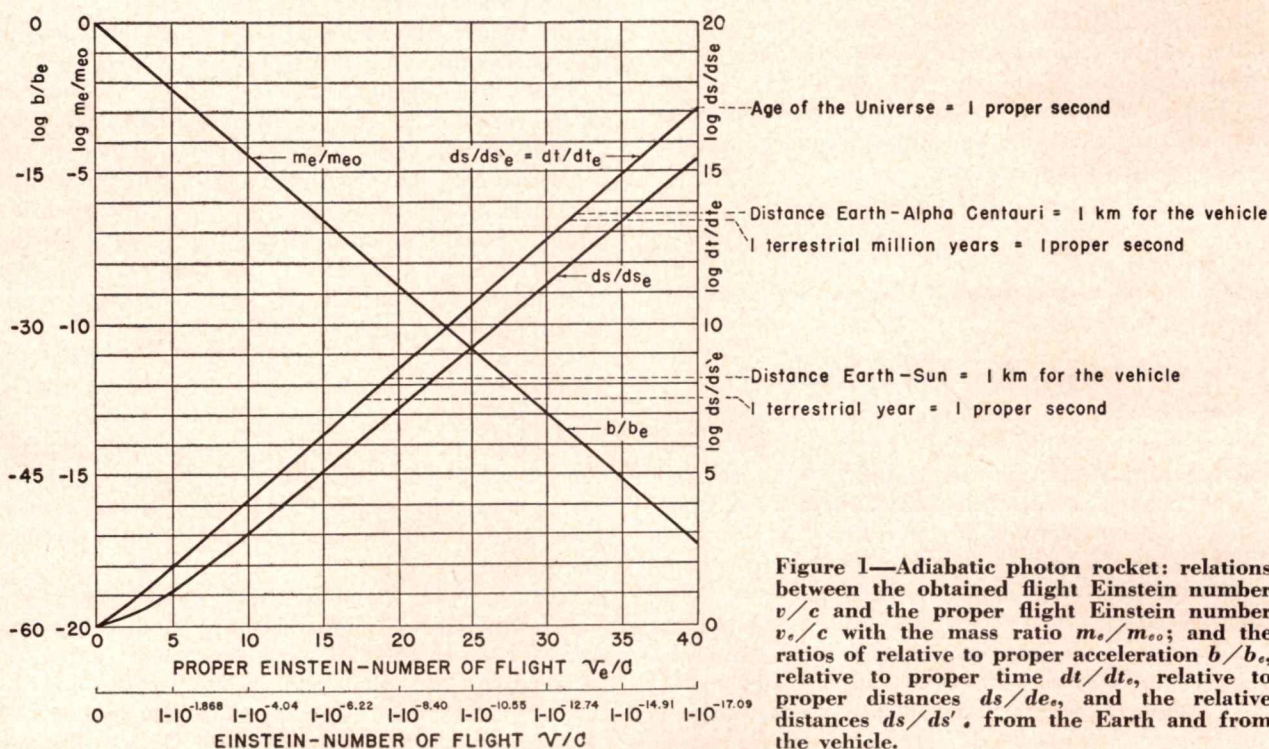


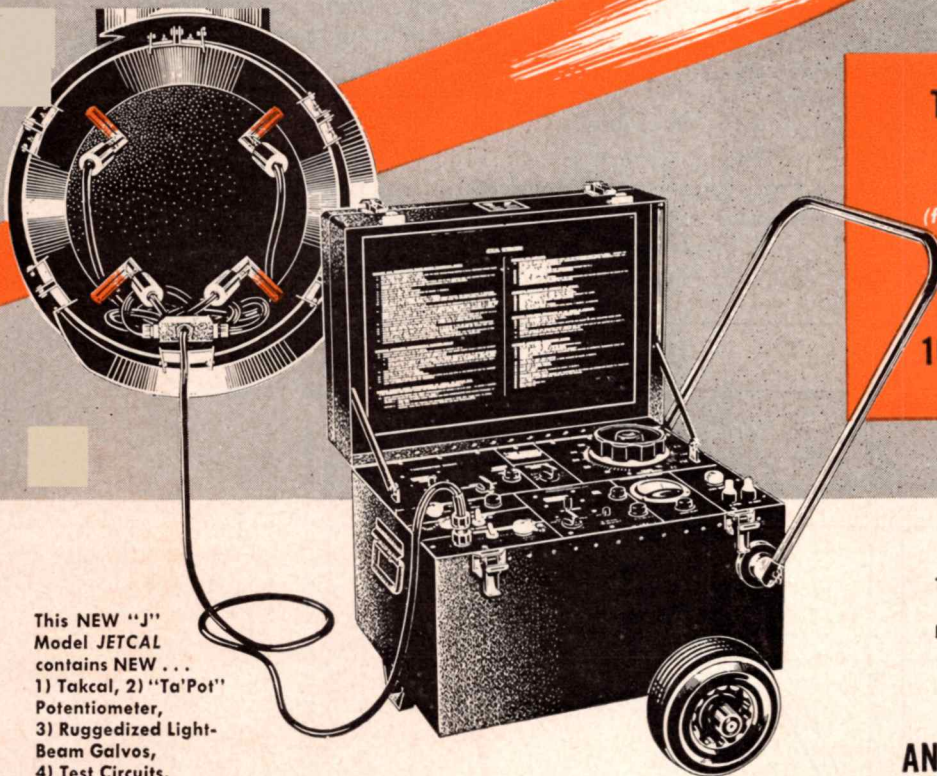
Figure 1—Adiabatic photon rocket: relations between the obtained flight Einstein number v_e/c and the proper flight Einstein number v/c with the mass ratio m_e/m_{e0} ; and the ratios of relative to proper acceleration b/b_e , relative to proper time dt/dt_e , relative to proper distances ds/ds_e , and the relative distances ds/ds'_e , from the Earth and from the vehicle.

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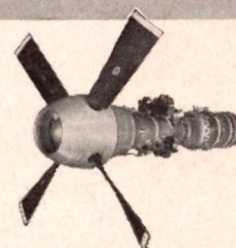
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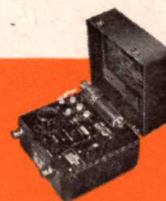


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photons. These beings thus would exist outside our world also in regard to space.

If our passenger could measure the distance of his travel, appearing to us as ten light years, from this photon, he would get the impression that he had traveled, during the time zero, also through a distance zero. Also, this strange state is never fully experienced by the crew of our space craft; however, it is quite closely approached for high proper Einstein numbers of the flight.

The relations of the relativistic time and length dilation, respectively, presented up to now, show exceedingly philosophical or even mythological aspects. A very concrete technological side of this problem with quite extraordinarily far-reaching technical importance opens with the consideration of the ratio ds/ds_e of the astronomical distance s to the proper paths s_e of the rocket. The astronomical distance s under all circumstances remains the basis for the planning of travel in space and the scale for its success. The proper distance s_e , however, is a fully fictive number in regard to its meaning as a distance, but according to Equations 1 and 5 it is the scale for the required fuel consumption of the vehicle.

The ratio of these two distances is presented in

Figure 1 as a third plot. It shows how immensely astronomical distances may increase over the proper distances for large Einstein numbers. This results in the fact that it is possible to pass through unlimited astronomical distances with quite finite proper distances and thus finite fuel consumption.

● ● Interstellar Flight

Only one of the innumerable thinkable examples for travel in space, which may be derived from the basic kinematic relations presented here, shall be considered quantitatively:

The travel over an astronomical distance S , in which the vehicle is accelerated during the first half of the travel with constant proper acceleration $b_e = 10 \text{ m/sec}^2$, and retarded during the second half of the travel with the same value of proper acceleration. The flow resistance of interstellar matter shall be regarded as negligible.

The kinematic and dynamic relations of the travel are easily obtained by integration of the above-mentioned basic relations, especially the quantities of interest here: proper time of the travel T_e , required mass ratio (m_e/m_{e0}) of the vehicle, and highest proper

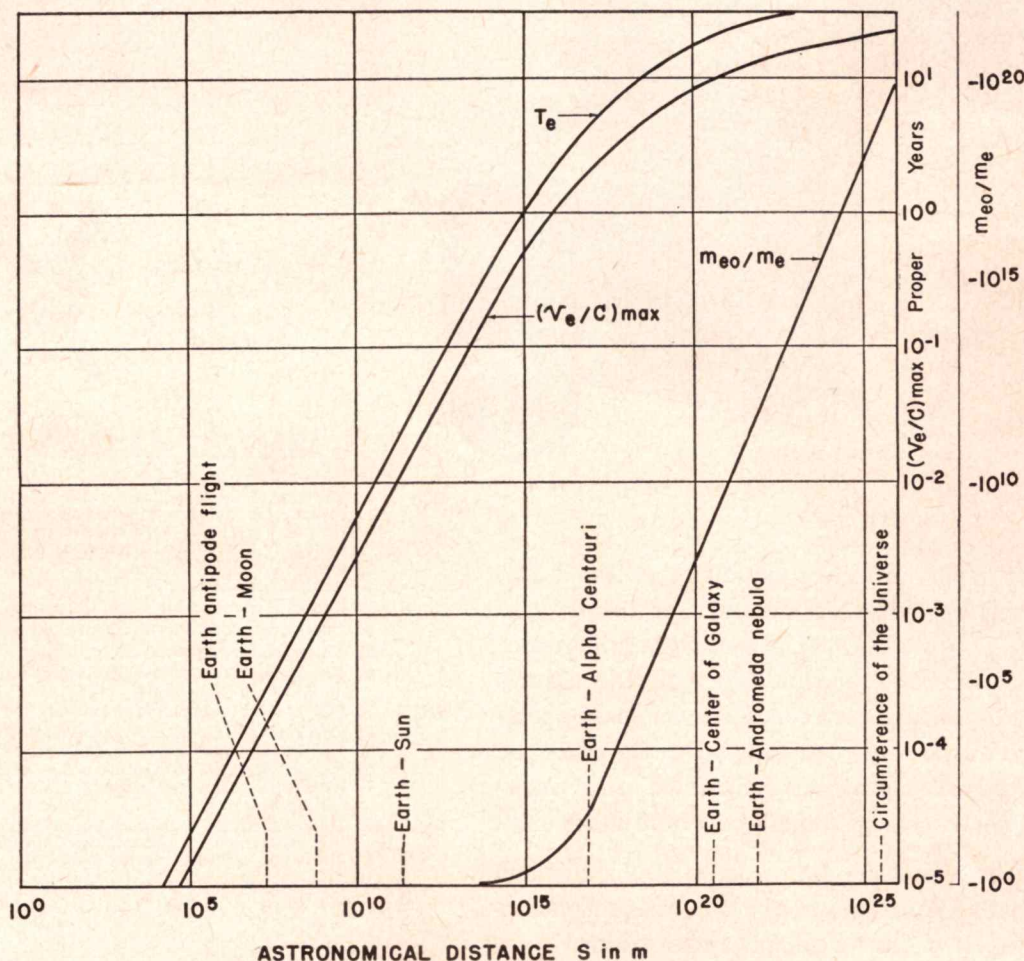


Figure 2—Adiabatic photon rocket: travels with proper acceleration $b_e = 10 \text{ m/sec}^2$ up to half the astronomical target distance S , and with proper deceleration $b_e = 10 \text{ m/sec}^2$ during the second half of this distance. Dependence of the required mass ratio m_{e0}/m_e , the total proper time of travel T_e and the maximum proper Einstein number $(v_e/c)_{max}$ occurring in the middle of the distance, on the total astronomical distance S .

Einstein number $(v_e/c)_{max}$ in the middle of the travel.

These three quantities are plotted in Figure 2 against all comprehensible astronomical distances S up to the assumed total circumference of the universe. They present ample material for further meditation.

In order to enliven the abscissas, several concrete examples of astronomical distances are indicated, such as those between two terrestrial antipodes (20,000 km), between Earth and Earth-Moon (400,000 km), between Earth and Sun (150-million km), between our solar system and the nearest one, that of Alpha-Centauri (4.3 light years), between the Sun and the center of our galaxy (30,000 light years), between the Sun and Andromeda nebula (750,000 light years), and finally the assumed total circumference of the universe (3-billion light years).

As is seen from Figure 2, the proper times of travel T_e under the assumptions made, range from 47.2 minutes to 41.9 years for these seven travels. In the last case, the crew will reasonably compare the relative astronomical distance of 3-billion light years with the 41.9 proper years, spent on the travel, and will believe they traveled with a mean velocity of 720 million times the velocity of light. As with our proper-velocity, this "proper time-velocity" is no real physical velocity, but is a suitable term to express the feelings of the crew. The crew encounters somewhat similar conditions, as with actual experiments with mesons, created by cosmic rays on the top of our atmosphere; the very short proper life-time of these mesons nevertheless is sufficient to cross the whole atmosphere and to be registered by instruments on the surface of the earth, thanks to relativistic time-dilation.

So the time span of one human life would be long enough for a travel around a total, static universe. Whether, however, our solar system would still exist at the time of the return of the crew is more than doubtful, as meanwhile more than three billion years have passed on it. During this time the crew of the space craft existed almost outside of our world-system with respect to time, hence in another world.

Furthermore, Figure 2 shows, in one of the just discussed parallel running curves, the highest proper Einstein number of the flight occurring in the middle of the travel.

In the case of artificial satellites, orbiting about the earth, the flight Mach number is about $v/a = 28$. In the case of the circumuniverse travel the proper Einstein-number was, for example $(v_e/c)_{max} = 22$, which means a length dilation of approximately $ds/ds' = 3 \cdot 10^9$, that is, the universe at this instant would appear to the crew to have a circumference of only about one light year. If they would not again retard their velocity, the craft would circumnavigate the universe once every proper year.

From the third curve (m_{eo}/m_e) in Figure 2, we see that for complete conversion of matter into radiation, the fuel consumption becomes noticeable in the graph only for travels essentially outside our solar system. For a travel in the described, though in no way economical manner, to our nearest neighboring solar system, Alpha-Centauri, the fuel mass would have

to be about 43 times the mass of the vehicle at the termination of flight, whence the travel lasts about 3.6 proper years or 6 terrestrial years, with an astronomical distance of 4.3 light years.

In no way is it the case that alien solar systems can be reached only in travels lasting through many generations, while numerous generations are born, grow up and again must die, until finally far descendants of the departing crew reach the destination.

Also, it is not that alien galaxies, hundreds of thousands of light years distant from us, can principally never be reached by us due to our limited life span, and that nature has banned us to remain on our small spot in the universe. One is reminded of a favorite sentence of Einstein's:

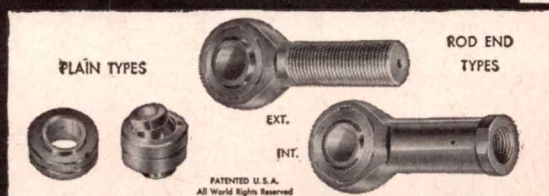
"Raffiniert ist unser Herre Gott—doch böse ist er nicht." ("Our God is particular—but He is not angry.")

No, we do not have to resign and humbly fold our hands in our laps. The infinite universe is small enough to be open to the initiative of everyone of us, open to its ultimate boundaries, everything accessible to human beings.

END

Based on paper presented at the International Conference on Jet Propulsion at Freudenstadt, February 8, 1956, and Report 5 of the "Forschungsinstitut für Physik der Strahlantriebe, Stuttgart" (Research Institute for Physics of Jet-Propulsion, Stuttgart-Germany), published by R. Oldenbourg, Munich (Germany) 1956.

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THE UTILITY of earth satellites is strongly related to their orbit stability, as influenced by the several perturbing forces acting on the satellite mass. Primary perturbations of the orbit path will be caused by (1) non-sphericity of the earth (oblateness caused by the earth's rotation about polar axis), (2) anomalies in the earth's crust (non-uniform distribution of the earth's mass, for example, mountain ranges, oceans and land masses) and (3) drag, due to immersion of the satellite in the earth's atmospheric envelope.

Secondary perturbations will be due to the variable, combined gravitational field of the earth-moon-sun system. However, this influence will be negligible with respect to the earth's oblateness and atmospheric drag.

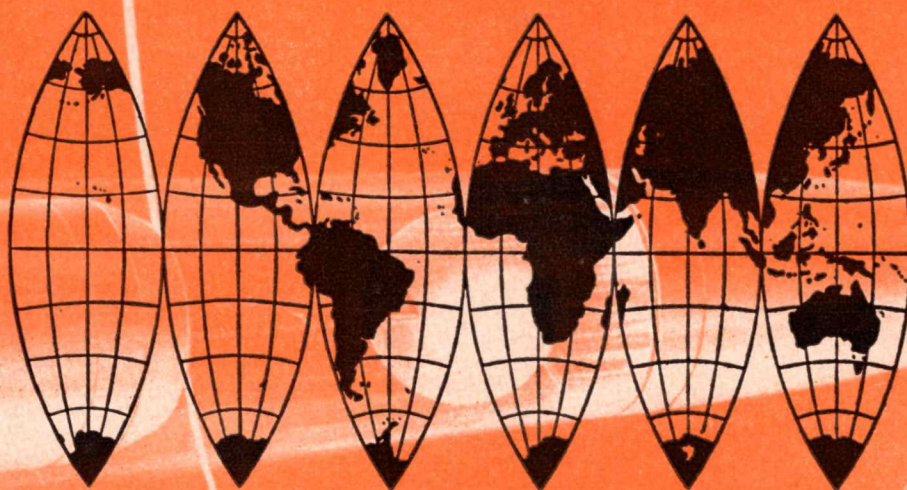
Oblateness, effective on polar orbiters and to a lesser degree for smaller inclination angles ($<90^\circ$) about the equator, and the atmospheric drag are of the greatest significance in disturbing the periodic motion of the satellite, whether on circular or elliptic orbits. For close orbits, a few hundred miles, these two factors result in continuously altering the orbit path. At higher altitudes, 400–500 miles, the drag attenuation reduces to a negligible amount. At slightly higher altitudes still, a few thousand miles, the earth's oblateness effect is negligible. At still greater altitudes the moon's influence is effective and would result in being the primary perturbation with all others of a negligible quantity.

One of the major objectives of the Earth Satellite Program is the determination of the atmospheric density variation with altitude. Direct experimental

measurement by pressure gauges within the satellite may not be practicable to ensure a continuous pressure record in the very tenuous upper regions beyond 100 miles. The most direct method to determine the density variation is simply to observe the perturbation to its orbit as a function of time. The drag perturbation would be differentiated from the other disturbances in that the drag would steadily dissipate energy of the satellite and retard its motion, whereas other disturbances would be periodic in nature and would principally influence other orbit characteristics such as phase and time relationship of apogee and perigee (oblateness causes perigee and apogee not to be 180° in phase) and orbit inclination as influenced by oblateness and lunar, solar and planetary gravitational influences.

Direct ground observation and tracking by optical and radar techniques will provide accurate satellite trajectory data as a function of time. Knowledge of the drag characteristics for the particular body shape and skin smoothness would, upon having the drag perturbation (loss of altitude and change in velocity), permit a precise density value to be computed. It is assumed that the apparent orbit changes, at least for orbits at 200–400 miles or more, would not be very great when considering or studying a fraction of a revolution about the earth by the satellite. In fact, for a relatively short segment of its trajectory it may prove difficult to discern the separate perturbation components as caused by earth oblateness, earth surface mass anomalies and solar system gravity effects.

Factors Affecting the LIFETIME OF EARTH



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Great Neck, New York

The orbital lifetimes for various proposed satellite designs have been calculated and plotted. The duration of a satellite's near circular motion around the earth is an indication of the influence of the atmospheric density existing at extreme altitudes.

Displacements from the initial trajectory after a complete revolution would indicate approximately the influence of only the drag aspect. Short observation periods (a fraction of one revolution) would be mainly useful in lifetime estimates if two satellites were available on orbit. By tracking both satellites, each having a different mass-area ratio, the rate of separation or the actual separation distance as a function of time between the satellites would indicate the density existing at the altitude.

Another method to measure the atmospheric density in the more tenuous regions, and which would serve to give a density value for a short observational period can possibly be achieved by using a body configuration with the center of pressure not at the c.g. position, or a dumb-bell shaped body. Knowing the polar moment of inertia and drag coefficient characteristics as a function of body orientation in regard to its flight path, the periodic motion of the satellite (oscillations about its c.g.) as influenced by the air drag, would indicate the density characteristics of the atmosphere.

The determination of orbit lifetimes can be determined to only the same degree of accuracy permitted by the known atmospheric density. This paper assumes that existing information, both experimental and theoretical, is valid.

The experimental program of *Project Vanguard* will provide precise orbit positional data, thus permitting a "backward" solution of the lifetime problem, that is, knowing the drag perturbation and drag coefficients, the density would be deduced.

SATELLITES

The general structure of the earth's atmosphere, from the surface to extreme altitudes, has been defined approximately by direct experimental measurements. *Viking*, V-2 and *Aerobee* rocket vehicles were used in the studies of upper atmosphere physics conducted at White Sands, New Mexico, and at other stations. Figure 1 shows the density, mean free path length and temperature variation from sea level to 1000 miles.

The structure of the atmosphere is usually assumed to consist of four main regions. These are the troposphere (from sea level up to about 10 miles), stratosphere (10 miles to 40 miles), ionosphere (40 miles to 400 miles) and the exosphere (400 miles outward to interplanetary space). The principal region of interest for determination of the flight characteristics of satellite vehicles is the ionosphere. Even in the lower region of the ionosphere, the atmospheric density is sufficient to retard free-flight orbital motion to less than one complete revolution about the earth. The upper limit of the ionosphere is perhaps the lower boundary for near-permanent satellite orbits, since the density is much less than at the lower limit of this region.

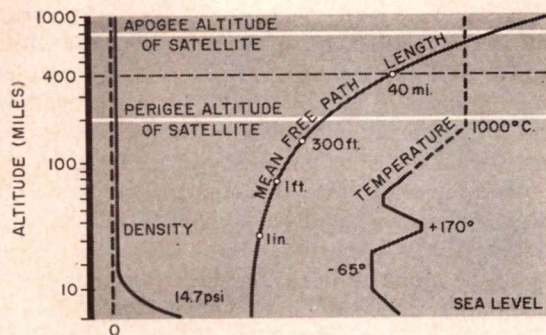


Figure 1—Density, mean free path length and temperature variations at atmosphere from sea level to 1000 miles altitude.

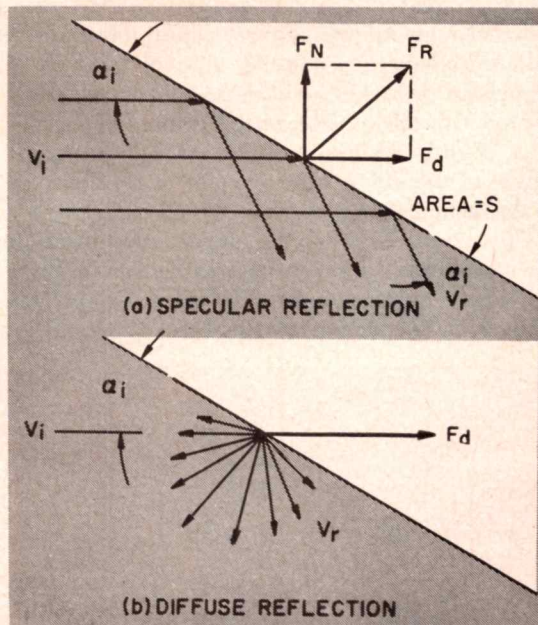


Figure 2—Specular and diffuse reflection mechanism in free molecule flow.

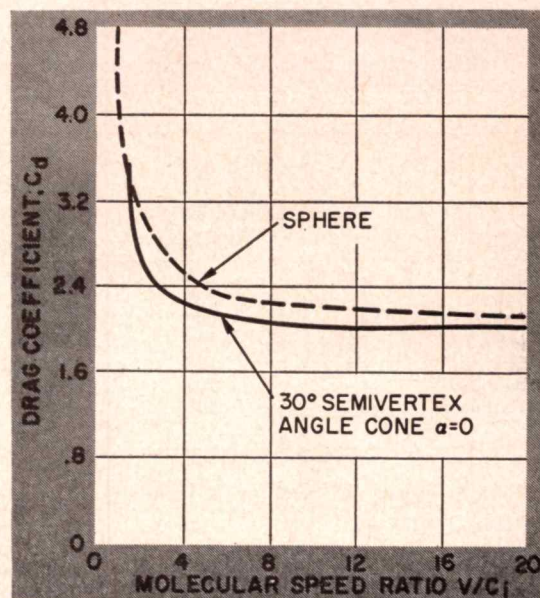


Figure 3 — Diffuse drag coefficient for sphere and cone (NACA TN 2423).

The air density ratio σ (ratio of density at any altitude to the density at sea level) at 50 miles altitude directly over the equator is 4.951×10^{-5} , whereas at 500 miles it is 2.68×10^{-12} . Bodies in motion at these altitudes are subjected to drag forces directly proportional to the respective density ratios. Thus the drag forces on a vehicle at the lower limit of 50 miles altitude will be about 20-million times the forces at 500 miles. It is interesting to note that about 98 percent of the air mass lies below the 20 mile level. The remaining two percent is then distributed from this level out to interplanetary space.

The composition of the lower region of the ionosphere, near 100 miles, is considered to be of nearly the same oxygen-nitrogen ratio as at sea level, or about 30 percent oxygen and 70 percent nitrogen. However, due to the absorption of ultraviolet solar radiation above this altitude, the molecular oxygen is dissociated and exists in this region only in the form of atomic particles. The nitrogen also dissociates, but at a slightly higher altitude. The mean molecular weight of the atmosphere remains at a value of about 24 throughout this region.

The temperature of the upper atmosphere below the ionosphere varies widely, as shown in Figure 1. The lower regions, below 70 miles, exhibit marked changes in the actual temperature of the air mole-

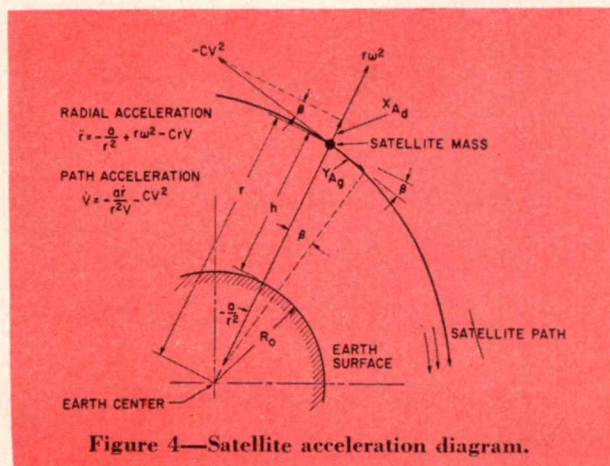


Figure 4—Satellite acceleration diagram.

TABLE I

CIRCULAR ORBITS

Body	m/a	h_c (miles)	t_L (days)
Sphere	0.01	200	8
Sphere	1	200	80
Sphere	10	200	800
MOUSE	1.273	190	47
Sphere ²	2.5	196	220
Satelloid ¹	11	100	18
Vanguard	0.283	200	20

ELLIPTIC ORBITS

Body	m/a	h_p (miles)	h_A (miles)	t_L (or rate)
Sphere	1.273	100	1000	66 mi/day
Sphere	"	150	"	300 mi/year
Sphere	"	200	"	50 mi/year
MOUSE	"	62	621	0.2 days
MOUSE	"	93	"	2.25 days
MOUSE	"	124	"	33.0 days

cules. Above 70 miles the temperature increases uniformly to an estimated value of 4000°F in the exosphere. This is considered a kinetic temperature, however, and does not have the same significance as temperature at the lower regions. The temperature level of a satellite on an orbit passing through the upper region of the ionosphere will not be increased appreciably when bombarded by the atomic particles in its path. The individual particles may possess high kinetic temperatures, but due to their low mass only a negligible net increase in the mean temperature of the satellite should result. Actually, the thermal equilibrium of a satellite is principally determined by the heat absorbed from the radiation of the sun and its ability to dissipate this heat by radiation. An equatorial orbit, due to the periodic eclipsing of the satellite by the earth as it passes from the sunlit side around to the darkened side, would result in a fluctuating temperature. On the other hand, a polar orbiting satellite might be exposed to continuous sunlight and consequently, a uniform temperature.

The influence of the upper atmosphere density and temperature on flight at these altitudes is possibly best shown by considering the mean free path of the atmospheric particles. The mean free path is defined as the average distance traveled by a single particle of air between collisions with other particles. This distance varies inversely with the atmospheric density and the characteristic dimensions of the particle.

At low altitudes the density is so great that the mean free path l of the gas is much smaller than the characteristic dimension or the boundary layer thickness enveloping aerodynamic bodies in flight. For conventional gas dynamics (subsonic and supersonic flow) the fluid is considered a continuous medium with the mean free path at sea level being about one-millionth of an inch.

At higher altitudes, near 40 miles (the lower limit of the ionosphere), the mean free path length is about one inch. The path length at an altitude of 75 miles becomes one foot. At higher altitudes the value of l exceeds even the length of the vehicle. For example, at 150 miles altitude, $l = 300$ feet, and at 400 miles the path length becomes about 40 miles. The atmosphere cannot be assumed to be a continuous medium throughout the major part of the ionosphere, but must be considered to be made up of independent particles. The concept of Reynolds number, which is significant in conventional gas dynamics at low altitudes, considers the relationship of the inertia and viscous forces. However, in a rarified gas flow (free molecule flow or the region of super-aerodynamics) the viscous action does not apply.

• • Circular Orbits

The lifetimes of satellite vehicles, Reference 1, or the duration of their near circular motion about the earth, is an indication of the influence of the atmospheric density existing at extreme altitudes. Although the density assumed to exist at altitudes above 100 miles is relatively small when compared to that at the earth's surface, it is sufficient to influence the flight path or orbit of the satellite over a long period of

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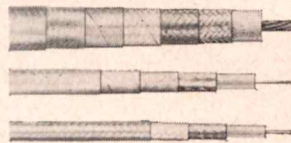
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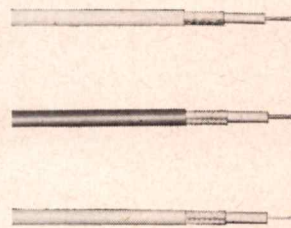


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time. The integrated effect of drag will gradually reduce the orbital altitude to the more dense regions of the atmosphere and finally terminate circular motion of the satellite. Although density is the predominant factor, the mechanism of free molecule flow drag also greatly influences the satellite lifetime. The characteristic of the exposed surface structure affects the magnitude of the drag coefficient. In the tenuous atmosphere surrounding the earth, the force acting on a surface is based on the assumption that the gas particles of the atmosphere are reflected principally in one of two ways. These are by the mechanisms of either specular or diffuse molecular reflection. The first of these, specular reflection, assumes that the incident streams of particles are elastically reflected from the exposed body surface like rubber balls, Figure 2a. The second, that of diffuse reflection, represents about 90 percent of the over-all drag. It assumes that the incident molecules are absorbed within the surface and later emitted at some velocity dependent upon the body temperature, Figure 2b. The resultant drag coefficient is affected by the ratio of these two drag components, that is, specular to diffuse reflection.

It is possible that research in the future may lead to a specularly reflecting surface material, thus diminishing the drag effects on vehicles in the rarefied atmosphere and resulting in greater lifetimes for these vehicles at the same altitudes. Figure 3 shows the drag coefficient for the diffuse case for spherical and conical shapes.

The velocity and accelerations which exist on the satellite body at any instant are shown in Figure 4.

The three forces, gravity, drag and centrifugal motion, act on a body in such a way as to constrain its motion to a spiral path from the initial conditions of near-circularity. If the atmosphere did not exist, the satellite would maintain its circular or elliptical motion continuously on a permanent orbit. This would

be the case for motion about airless bodies such as the moon, or simply at altitudes above the earth where the atmosphere does not exist in any appreciable amount, that is, above 400-500 miles. Figure 5 illustrates the influence of drag on the elliptic orbit path of a satellite, Reference 2.

The differential equations of motion, expressed in polar coordinates are as follows:

$$\ddot{r} = r\omega^2 - \frac{a}{r^2} - cr\dot{V} \quad (1)$$

$$\dot{V} = \frac{-ar}{Vr^2} - cV^2 \quad (2)$$

$$\dot{\omega} = \frac{-2r\dot{\omega}}{r} - cV\omega \quad (3)$$

$$V^2 = \dot{r}^2 + (r\omega)^2 \quad (4)$$

Equations 1 and 4 respectively, denote the resultant acceleration of the satellite body along the radius vector (Figure 4), $\ddot{r}$, the path acceleration $\dot{V}$, the angular acceleration of the radius vector $\dot{\omega}$, and path velocity V .

The components of Equations 1 and 4 have the following significance:

- $r\omega^2$ = centrifugal acceleration along radius vector.
- $-\frac{a}{r^2}$ = gravitational acceleration along radius vector.
- $-cr\dot{V}$ = drag acceleration component along radius vector (X_A).
- $-cV^2$ = drag acceleration along flight path.
- $-\frac{ar}{Vr^2}$ = gravitational acceleration along flight path.

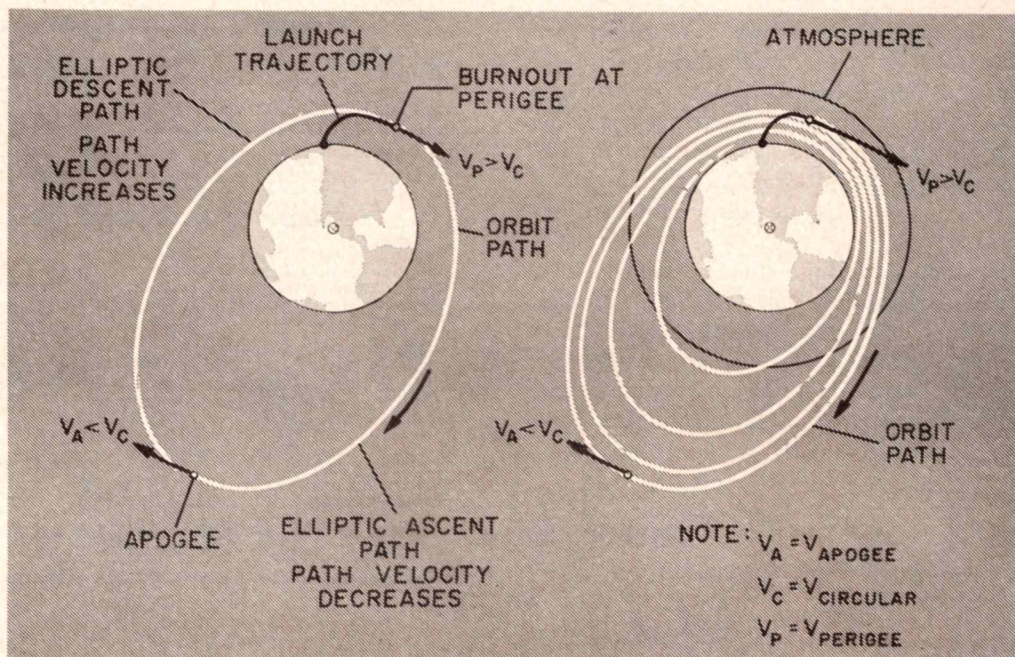
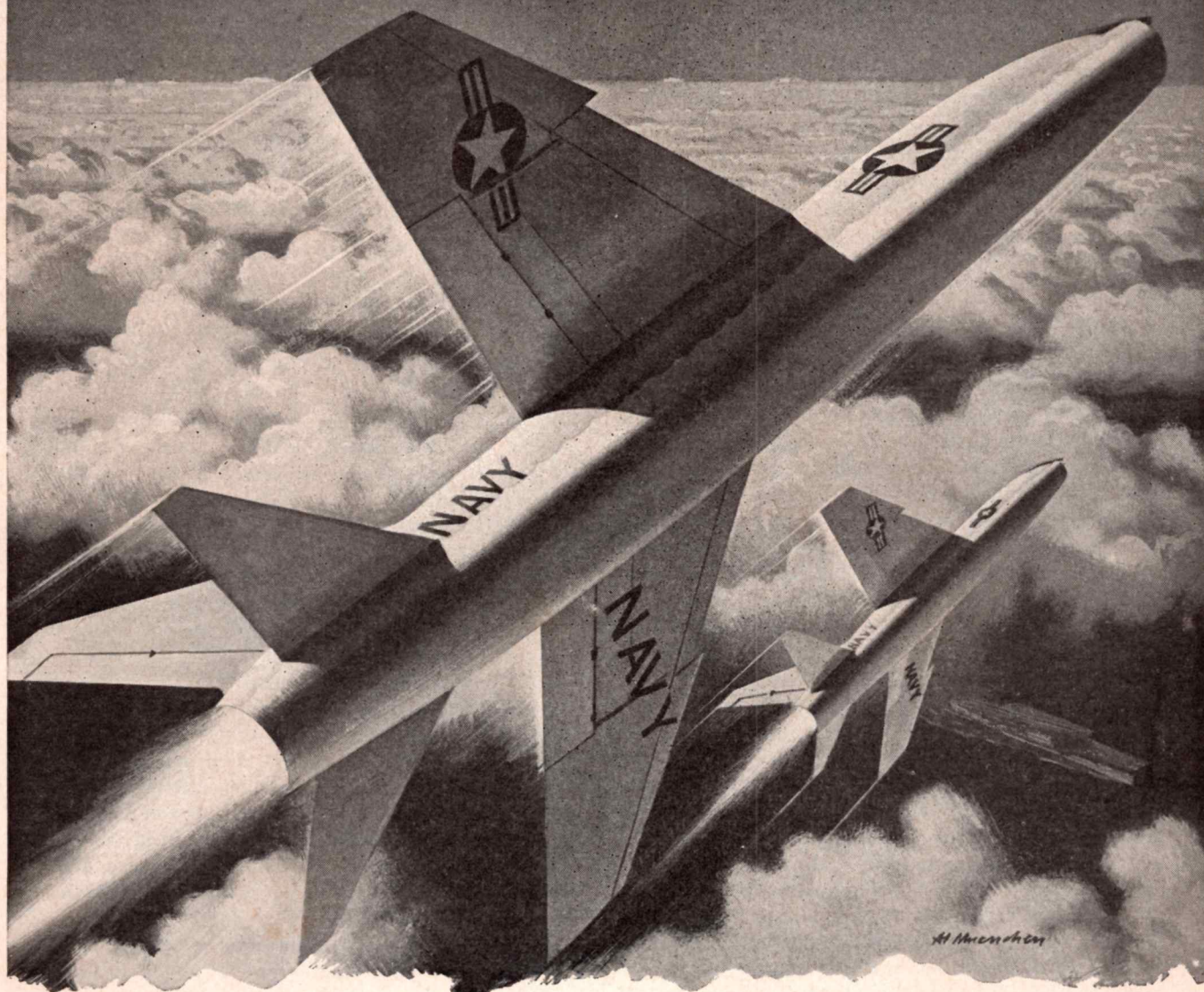


Figure 5—Elliptic orbit paths showing the influence of atmosphere on the satellite trajectory.

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R_o = mean radius of earth.

g_o = earth surface value of acceleration of gravity.

Series expansion of the exponential term reduces Equation 5 to

$$r_1 \cong r_o [1 - 2c_1 (K_1 a/r_1)^{1/2} \cdot (t_o - t_1)]$$

Consideration of the constants in Equation 5 for the altitudes of interest of about 4000 miles shows that K_1 is nearly equal to 1 and $V^2 = g_o R_o^2 / r_1 = a/r_1$. The time interval Δt_n for an arbitrary altitude loss $\Delta r_n = r_o - r_1$ is

$$\Delta t_{(n=1)} = t_1 - t_o = \frac{r_o - r_1}{2C r_o V_o} \quad (6)$$

where the subscript n denotes the interval considered and 0 and 1 are the initial and final values for r , V and t . The total satellite lifetime, t_L , from initiation of near-circularity to the surface, is then the summation of the Δt 's. Equation 6 is shown plotted on Figures 6 and 7 for the special case of a sphere or cone having a diffuse drag coefficient of $C_D = 2$, and mass-area values of 0.1, 1.0 and 10.0 slugs/ft.² Indicated on Figures 6 and 7 are the lifetime characteristics based on the theoretical density data of Grimmer (Reference 3) and the experimental density data of La Gow, Havens and Koll (Reference 8) extrapolated above 100 miles.

The first two terms on the right of Equation 1 represent the general equation of planetary motion. The third term, $-c^2 V$, is the forcing function, due to the drag that perturbs the planetary motion (periodic) to a spiral path. Further, Equation 1 for the case of zero angular rotation of the body about the earth, that is, $\omega = 0$, then becomes the classical representation describing motion of a body falling within a central force field in a resisting medium (free fall of a body along a radius vector of the earth within the atmosphere).

An approximate solution to the non-linear differential Equations 1 to 4 was accomplished by a step by step procedure assuming that the path velocity does

not vary appreciably for a small interval of Δr (increment radius vector).

The solution of Equations 1 to 4 showing the altitude-time relationship for the orbit decay, for an interval of Δr , is approximately given by Equation 5 below.

$$r_1 \cong r_o \exp [-2c_1 (K_1 a/r_1)^{1/2} (t_o - t_1)] \quad (5)$$

where,

$$K_1 = 1 / (1 - 6c_1^2 - r_1^2)$$

$$c_1 = [(C_D S \rho) / 2]_{ave}^{o-1}$$

$$r_o = \text{satellite altitude at } t = t_o$$

$$r_1 = \text{satellite altitude at } t = t_1$$

$$a = g_o R_o^2$$

One proposed spherical satellite of the *Vanguard* project, having a diameter of 21 inches and weighing 22 pounds, is estimated to have a lifetime of about 20 days if placed on a circular orbit at 200 miles. Recent statements indicate that an eccentric (elliptic) orbit may actually result, having a perigee of 200-400 miles and an apogee as great as 800 miles or more. This orbit would increase the satellite's duration by increasing the 20-day circular orbit lifetime by a multiple of perhaps as much as ten.

Lifetimes are severely influenced by the mass-area ratio. This parameter is indicative of the energy per unit of cross-sectional area available for dissipation by the drag forces. Bodies of large mass, but small cross-sectional areas, have longer lifetimes. Mass-area ratios of the order of ten indicate the possibility of lifetimes bordering on years, even at altitudes of only 200 miles. Above 500 miles, permanent orbits may be assumed to occur for most satellite applications.

A precise analysis based on the true orbit perturbations caused by the drag forces are not readily calculable. For the case of eccentric or elliptic orbits, the orbit lifetime is similarly influenced by the same

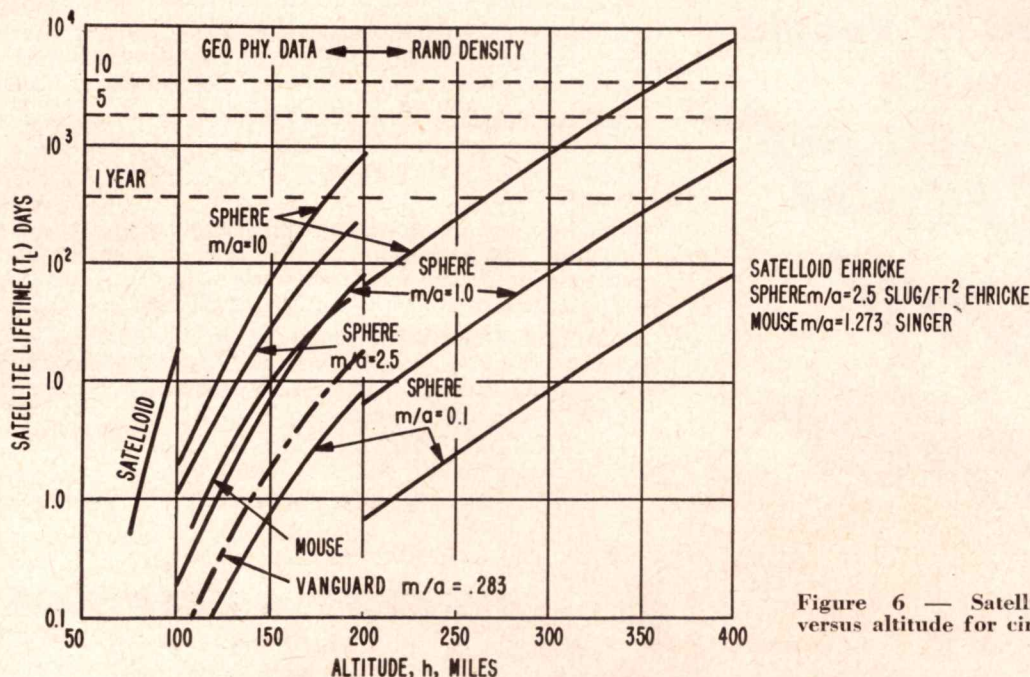


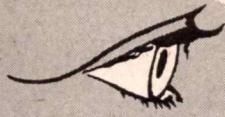
Figure 6 — Satellite lifetime versus altitude for circular orbits.

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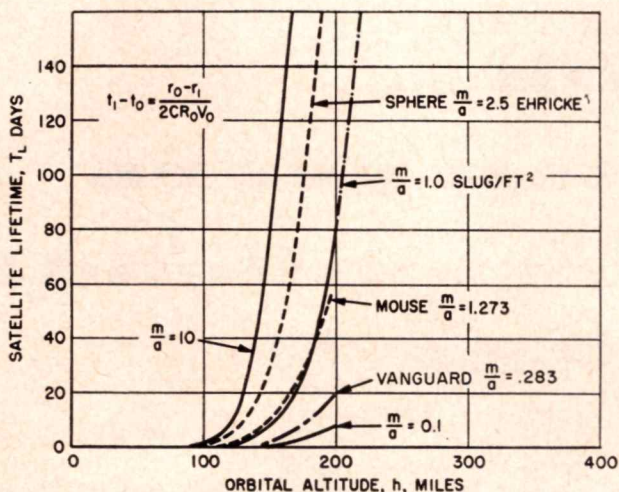


Figure 7—Satellite lifetime versus altitude for circular orbits (rectangular coordinates).

factors as for circular flight. However, the problem is further complicated by the periodic variation in density with altitude extremes of the orbit. For a highly eccentric orbit, the apogee would be sufficiently large to permit the assumption of zero drag at apogee to be a reasonable approximation. Consequently, the satellite would undergo a retardation only at the perigee where the denser region of the atmosphere is met, thus consuming part of the initial total energy. For an elliptic orbit having an initial apogee at 1000 miles and perigee at 100 miles, then considering the drag retardation occurring only at perigee will reduce the apogee and perigee point on each successive revolution around the earth. A further approximation to the determination of the elliptic orbit lifetime is made

by assuming that continued orbiting of the vehicle does not appreciably reduce the point of perigee; that is, the perigee point remains fixed throughout the orbit decay with the apogee point being reduced by an increment Δh_A , proportional to the drag energy E_d , occurring during immersion in the atmosphere.

The lifetime based on these simple assumptions can only be construed as a very approximate estimate. The time to decay from the 1000 mile apogee altitude for the special cases having 100, 150 and 200 mile perigees are shown on Figure 8. For $h_p = 200$ miles the satellite loses altitude at the rate of about 50 miles per year; at 150 miles the rate is 300 miles per year, and at 100 miles is 66 miles per day.

The characteristics for the *MOUSE* showing the lifetimes for the low apogee altitude of 620 miles also appear on Figure 8. These were estimated similarly by summing only the drag energy at perigee. The effect of increasing the apogee altitude from 620 miles to 1000 miles markedly increases the lifetime.

In summary, Table 1 lists the lifetime data for circular and elliptic orbits. END

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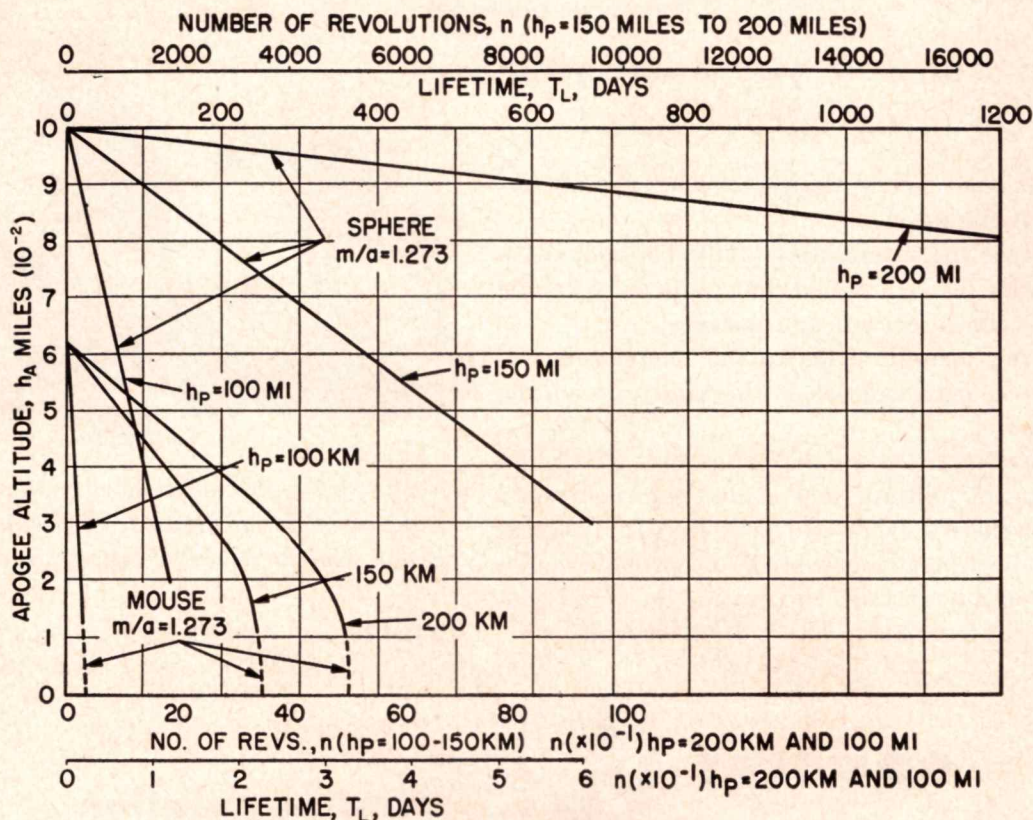
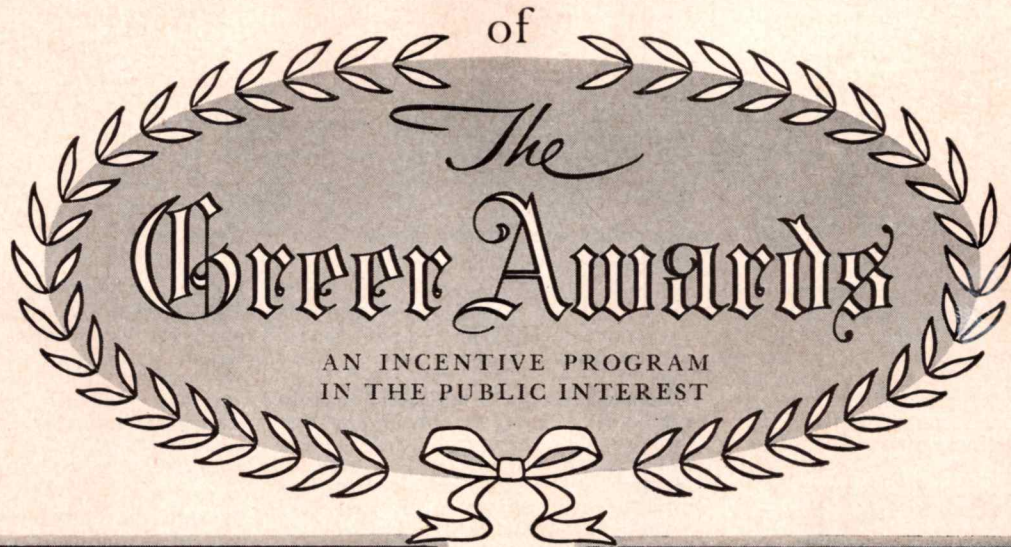


Figure 8—Satellite lifetime from elliptic orbits.

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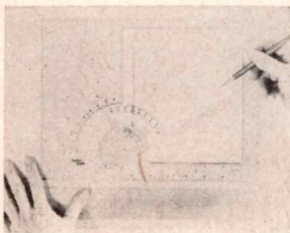
Gyro. American Gyro Corporation's Model F10A-1 free gyro is small enough to meet space requirements for missile applications and capable of delivering full efficiency in both missile and piloted aircraft systems, according to the manufacturer. Performs to specifications with vibration of 10 g's from 10 to 25000 cps. (E-1)



Tape Transports. Two new portable transports for magnetic tape data recording in missiles and jets under adverse environmental conditions now available from Davies Laboratories, Inc. Combined with suitable Davies housings and electronic equipment, each serves as a complete mobile tape recording system with provisions for up to 26 or more data channels, depending on system characteristics. (E-2)

Actuator. New 1 lb linear actuator manufactured by Airborne Accessories Corp. includes radio noise filter, limit switches externally adjustable throughout entire stroke range, positive stops and anti-rotation device. Meets MIL-A-8064 specification. (E-3)

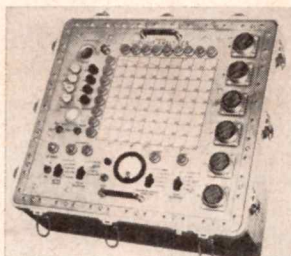
Wire Programming Machine. Designed and built by Torrance facility of Douglas Aircraft Company's El Segundo Div., machine measures, cuts, stamps and strips wire ends in one continuous operation at the rate of 40 ft/min, a job formerly performed manually at only 8 ft/min, according to the manufacturer. Unit has maximum potential of 100 ft/min and is accurate to 1/4 in. in 100 ft lengths. (E-4)



Drawing Instrument. Combines 12 basic features including 1/8 in. scale, 1/4 in. scale, 12-in. ruler, double calibrated 180° adjustable protractor, 1/4 in. pointers, and templates for making circles, french curves and common

symbols, Handee - Dandee Products says it is only instrument with which successive parallel lines equally spaced can be drawn. (E-5)

Electronic Servo Amplifiers. Servomechanisms, Inc., announces new line of 400 cycle electronic servo amplifiers designed to drive a wide range of instrument motors in aircraft and missile servo systems. Hermetically sealed, plug-in units are available in 2, 4 and 10 w ranges. Also available as companion equipment is a complete line of 400 cycle power supplies and modulators, designed by Eastern Components Div. to meet applicable USAF specifications. (E-6)



Circuit Analyzer. Designed expressly and exclusively for military use, Model 144NX automatic electrical circuit analyzer is an adaptation of DIT-MCO Model 200 circuit analyzer. Repackaged in lightweight, water-tight fibre glass case, unit tests complex electrical systems in aircraft, guided missile, radar, computers and servomechanisms systems at up to 144 circuits in seconds. (E-7)

Dispenser for Plastics. Mass production techniques in the application of cellular foamed plastics to the aircraft industry are now possible with the Nopcometer, according to Nopec Chemical Company, developers of this new automatic metering, mixing and dispensing unit. Machine delivers predetermined charge of foam of any required density at varying rates up to 15 lb/min. (E-8)

Teflon-Coated Glass Yarn. Glass yarn previously coated with duPont's Teflon after braiding is now receiving the coating directly to the glass before braiding, thereby giving each strand of glass individual protection, in addition to the overall protection. L.O.F. Glass Fibers Company says the new yarn is of considerable advantage in the aircraft industry, where aircraft cables have to be pulled through small and sometimes rough openings. Yarn is inert to solvents and most corrosive chemicals and has a water absorption so low it can be considered zero, according to manufacturer. (E-9)

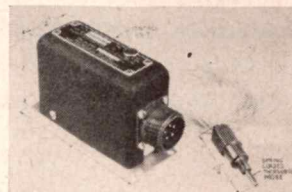
Combination Test Stand. Greer Hydraulics, Inc., says new machine, des-

igned HPM50-2H, performs the same course of tests formerly requiring two different machines for testing hydraulic pump and motor systems of all types aircraft. Unit measures performance of variable displacement pumps and motors up to 75 hp, hydraulic flows from 1.4 to 41 gpm, and pressures to 3500 psi. (E-10)

Transistors. Used to measure the critical temperature of exhaust in jet engines by means of a compact device enclosed in a panel indicator case 2 in. in diameter, these transistors feature isolation from lead effects in the thermocouple system and capability for actuating auxiliary temperature functions. Minneapolis-Honeywell Regulator Company. (E-11)

Solid Carbide Cutter. Martin has designed a solid carbide cutter which routes panel cutouts of many different combinations of materials used in today's aircraft. Previously, combinations of many dissimilar materials meant the rapid breakdown of high-speed steel routing cutters. According to Martin, new cutter has routed over 500 cutouts in panels of laminated phenol-fiber, fiber glass and dural without sign of breakdown. (E-12)

Stretch-Wrap Press. According to Convair-San Diego, newly installed press has doubled production of sheet metal parts made in this manner for aircraft. Known as the Hufford stretch-wrap forming machine, it can handle contour curve forms of various shapes. Thickness range of sheets that can be handled is from 0.016 to 1/4 in. Convair says press can produce larger aircraft skin segments, thereby reducing number of parts and rivets required in an airplane. (E-13)



Aircraft Windshield Temperature Monitor. To prevent overheating and damage to aircraft windshields which are heated to prevent icing and fogging, Fenwal Incorporated has developed a windshield overheat detection unit which can also be used for temperature control. Consists of two components: sensing probe containing thermistor detector and compact control box containing amplifier and control circuit. Thermistor detector is adjustable to operate over range of 170-270° F with maximum differential of ±10° F. (E-14)

Tie-Rod Assemblies. Two types of stainless steel bellows tie-rod assem-

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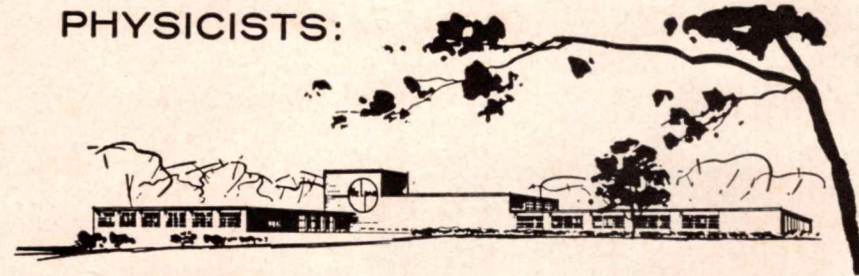
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blies for use in pneumatic ducting systems of turbojet and turboprop aircraft are being produced by the Metal Products Manufacturing Division of Arrowhead Rubber Company. Used to control thermal growth of ducting systems by absorbing relative movements between two points by angular deflections, both assemblies are available in all diameters from 1 to 15 in. (E-15)

Autopower. New system in the field of automatic controls which operates aircraft engine throttles during landing approach can make airplane climb, glide or maintain level flight as required, with automatic adjustment of required engine power, according to Safe Flight Instrument Corporation, developers of Autopower. (E-16)

Chemical Rain Repellent. Developed for airplanes to obviate mechanical windshield wipers which are impractical in high speed jet aircraft, repellent is made up essentially of silicones and a combination of natural and synthetic waxes. Resists rain by setting up a hard coating on the glass or plastic which makes water behave more like heavy beads of mercury; it is swept off in droplet form with the help of the wind and speed of the plane. Each application lasts for several days of heavy rain, and then windshield is cleaned and recoated. Foster D. Snell, Inc. (E-17)

Air Motor. Bendix-Pacific announces a new air motor of a constant displacement rotary vane design for use as a prime mover to operate an alternator and a hydraulic pump for an electro-hydraulic supply to power a missile control system. Motor has been completely qualified for missile applications over an ambient range of -20°F to 160°F and accelerations of 60 g, according to the manufacturer. (E-18)

Marker-Beacon Receiver. First all-transistor electronic marker-beacon receiver for commercial and military aircraft is the smallest and lightest ever developed, according to the manufacturer, RCA. This 15 oz unit requires only $\frac{3}{4}$ w and will operate at unpressurized altitudes of up to 40,000 ft and at temperatures from -65°F to 160°F . (E-19)

Silicone Rubber. First silicon rubber compounds to have same shrinkage as organic rubber have been added to standard product line of Silicone Products Department of General Electric Company. Designated SE-361, SE-371 and SE-381, these Class 300 compounds make possible the molding of silicone rubber parts in same molds used for organic rubber parts. Manufacturer also claims they permit specification of closer tolerances. (E-20)

Air Control Assembly. New air control assembly manufactured by Air-matic Valve, Inc. automatically filter, regulates and lubricates compressed air used in operation of pneumatic equipment. Automatic drain trap attached to bottom of filter collects moisture from filter, eliminating periodic draining maintenance. (E-21)

Plastic. Optipeel, new forming process, permits forming of acrylic can-



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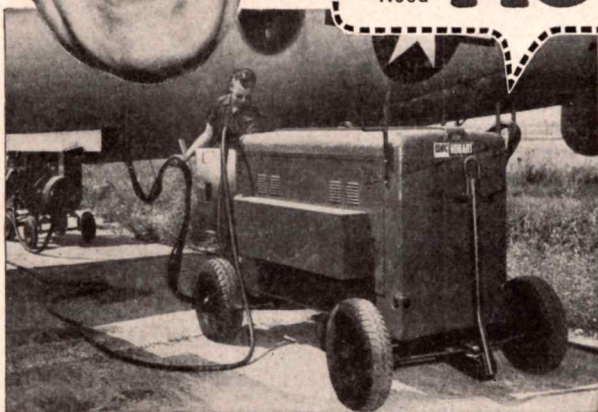
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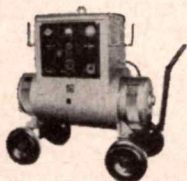
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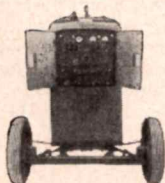
DC



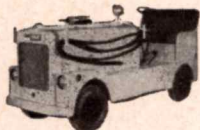
The increasing use of 400 cycle power in aircraft—both military and commercial—has created a need for closely regulated, dependable 400 cycle generators of the industrial type. Hobart meets these needs with the following complete lines for ground tests and checks.



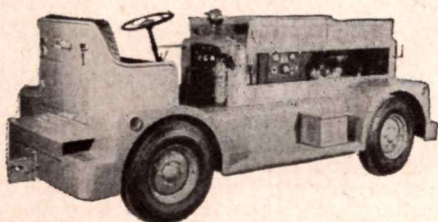
Electric Motor Driven: Induction motor driven 400 cycle generators with capacities of 3 to 30 KW. Synchronous motor driven generators with capacities of 5 to 100 KW. Furnished complete with all controls and instruments. Ideal for hanger, test line, or missile launchers.



Gas Engine Driven: Commercial and military models are in production. 400 cycle AC generators with capacities from 10 to 60 KVA, gas engine driven. 75 and 90 KW with Diesel engine drive.



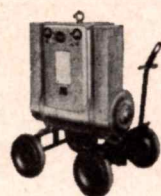
Self-Propelled: For busy airports and test areas, this self-propelled design saves space and time. 400 cycle AC generators of this type are available in the same capacities as trailer type above.



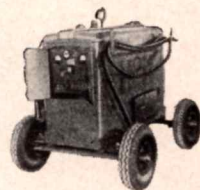
Combination AC-DC generators also available: (unit illustrated has a capacity of 30 KVA 400 cycle AC and 6 KW 28 volt DC). If you have special requirements for both 400 cycle AC and 28 volt DC from the same unit, you'll probably find Hobart has a unit already designed close to your requirement. If not, we will be glad to work with you to get exactly what you need.

A dependable source of regulated 28 volt DC power is still required for many commercial and military aircraft and missile applications. Hobart generators, designed for the specific job you have, gives you many time and cost saving advantages.

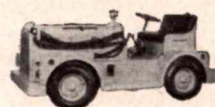
Electric Motor Driven: Capacities of 50 to 1500 amperes at 28 volts DC. Also available with current limiting or constant current features for jet engine starting. For use where electric power is available. Low cost—dependable.



Gas Engine Driven: Capacities of 200 to 1500 ampere for jet or reciprocating engine starting and aircraft testing. For flight line use away from electric power. Complete with all controls, DC cable and portable mounting.



Self-Propelled: This maneuverable ground power generator gets to the job under its own power. Saves cost and maintenance of separate tractors. Capacities of 600, 1000, 1500 amperes are in standard production.



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opies or other contoured parts to any desired shape without distortion and with good optical properties, according to the developer, Plastic Age Sales, Inc. Prior to forming plastic sheet is coated with smooth, pliable plastic material called Optijel, which becomes integral part of basic plastic sheet and absorbs all impurities, imperfections and other defects. After cooling the marred coating of Optijel is peeled off, leaving surface of formed article smooth and unblemished. (E-22)

Miniature Pulse Transformers. New series of miniature pulse transformers hermetically sealed by vacuum mold epoxy process are suited to wide variety of blocking oscillator, interstage and low level modulator applications, according to United Transformer Company. Designed for service from -70°C to $+130^{\circ}\text{C}$ and meet MIL-T-27 specifications. (E-23)

Acceleration-Sensitive Switch. Suitable for use where instruments, controls or safety devices are required to operate at a pre-determined acceleration level, Maxson Instruments acceleration-sensitive switch has snap-acting element capable of being set, in manufacture, to open or close when desired g level is reached. Can be furnished to operate at any level from 2.5 to 15g absolute. (E-24)

Check-Relief Valve for Liquid Oxygen. Anderson, Greenwood & Co. has developed valve to maintain a balanced load between converters in liquid oxygen systems having multi-converter installations. Conforms to tentative specification MIL-V-25513, which has replaced specification MIL-V-9029. (E-25)

Slip-Squeeze Nuts. New type slip-squeeze nut promises to save much time and money in the construction of plaster models and mockups, according to the developer, Convair-San Diego. New type nuts can be located immediately on any desired position on the rod, slipped into position and squeezed tight in one easy operation. Can be produced with any desired perimeter and the thread size of any desired material. (E-26)

Aerial Photo Interpretation Kit. Designed by Gordon Enterprises for use in analyzing aerial photographs, kit contains all devices necessary for viewing and precise measuring of aerial photographs. Includes three special folding stereoscopes, contour measuring devices, height finder, special drawing instruments, aerial photographic slide rules and scales, and all necessary accessory tools. (E-27)

Potentiometer. Especially adapted to flight test, servo feedback and telemetering applications, new MINCO Engineering and manufacturing potentiometer is gasket and O-ring sealed against immersion to 15 psi. Rotary sector pot designed to withstand up to 40 lb side load on the shaft while operating. (E-28)

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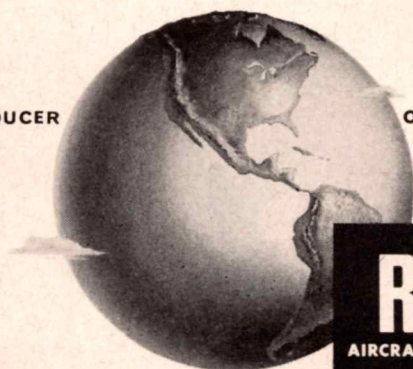
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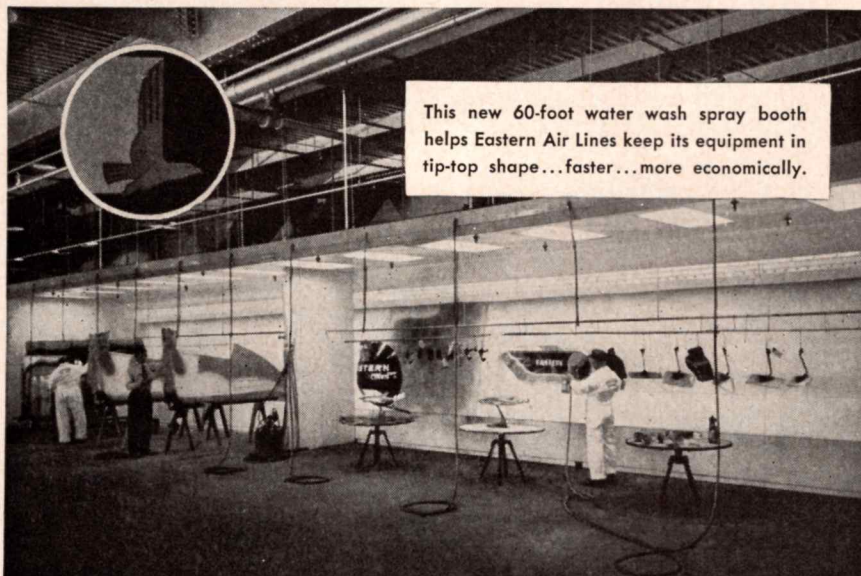
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"The ventilation is very good and the five-time washing of the air is excellent"

"We in Eastern Air Lines have found our new Binks spray booth to be quite satisfactory. It has been able to handle all types of our work. The ventilation is very good, and the water system, water curtain, and five water washes of the air are excellent."

These are the words of W. S. Tefft, Superintendent of Plane Overhaul at Eastern Air Line's offices in Miami, Florida. The equipment is a 60-foot Binks Dynaprecipitor Water Wash Spray Booth designed to accommodate everything from sizeable plane assemblies to the smallest of parts.

All paint overspray and fumes are drawn into the booth on a steady stream of air that does not cause any "drift." The contaminated air is scrubbed thoroughly 5 times before it is exhausted out-of-doors...free of paint.

Booths of this kind are fully approved by local authorities and by the insurance companies. They not only make for much cleaner and healthful working conditions in the shop, but also speed up finishing and lower maintenance costs. Down time for cleaning is reduced to a minimum because the paint is washed out of the air and is collected in the water pan for easy reclamation or disposal. Exhaust fans stay cleaner and balanced.

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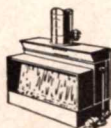
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ance aircraft in pitch, roll and yaw can be reproduced by the Color Television Incorporated 3-axis flight simulator. Voltage analogs of the vectors representing these factors are fed as individual command signals to the hydraulically driven flight table so that its position continuously corresponds to the velocities and accelerations defined by the input signals.

(E-29)

Servo Amplifier. New smaller transistorized servo amplifier, encapsulated in an epoxy resin, features high power gain of 10³:1, yet measures only 1½ in. x 1½ in. x 1 in., according to John Oster Manufacturing Co., Avionic Division. Applications include guided missiles and computers. (E-30)

Servo. Type 2V-3362, which measures ½ in. x 1 in. diameter, is said by John Oster Manufacturing Co. to be virtually as powerful as a size 10 servo twice as large. At room temperature motor starts with 18 v on fixed phase and with 0.4 v on control phase. (E-31)

Seam Welder. Sciaky Bros., Inc. announce new design of air operated, press type Sciaky MP 1 single phase seam welder which is one of a series of sizes ranging from 1 through 5. Available in 50 and 75 KVA at 50 percent duty cycle. (E-32)

Blower. New fan-blower unit for airborne application, which compensates for low air density by increasing blower speeds, is announced by Induction Motors Corp. Unit, known as BC-2914 F-1, has been designed especially to provide higher cfm rates at upper altitudes. At sea level will provide 8000 rpm, with 210 cfm at 2 in. back pressure. (E-33)

Compression Tester. Built specifically for testing complete aircraft wheel assemblies, new 500,000 lb capacity compression testing machine, developed by Tinius Olsen Testing Machine Company, is designed so that any one of three testing ranges—full capacity, 1/5 capacity and 1/20 capacity—is immediately available without stopping the test. (E-34)

Aircraft Crane. Portable crane designed specifically for making rapid engine and heavy aircraft component changes features unique manual winch which permits a single man to change entire assemblies, regardless of whether the plane is inside or outside the hangar. Crane needs no electrical power, has hook clearance of 22 ft and will accommodate any commercial aircraft, according to Safway Steel Products, Inc. (E-35)

Locknuts. For fastening applications where space allowables are reduced to a minimum, new line of miniature self-locking anchor nuts has been developed by Elastic Stop Nut Corporation of America. Available in three designs — corner anchor, two-lug anchor nut plate and one-lug anchor—and four thread sizes—6-32, 8-32, 10-32 and ¼-28. (E-36)

Insulating Compounds. Two new thermosetting, self-curing polyisocyanate foams for insulating and reinforcing voids between structural members are

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Men with mature engineering judgment and at least 3 to 5 years' experience in late model aircraft power plant analysis and design plus, in some cases, a proven ability in supervision.

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now available from Adhesive and Coatings Division, Minnesota Mining and Manufacturing Co. Both compounds are a two-part liquid formulation which, when mixed with a catalyst under proper conditions, can be foamed in place to produce a rigid cellular material that will not break loose, settle or sag, according to manufacturer. (E-37)

Lubricant. New, instant drying Spray Graph provides effective lubrication at temperatures ranging from -100°F to $+800^{\circ}\text{F}$ and reduces oxidation, corrosion and friction, according to American Resin Corporation. (E-38)

Capacitors. Two new Teflon dielectric capacitors specifically designed for high temperature use in guided missiles and other airborne applications are smaller in size than any other capacitors designed to give the same electrical characteristics at temperature ranges from -70°C to $+200^{\circ}\text{C}$, according to Condenser Products Company. (E-39)

Tank Liner. The H. H. Davis Company says Tankite, new development for use as tank liner in storage tanks and aircraft, has been found after 18 months of testing to be unaffected in that time by petroleum products from lubricating oils up to and including 100 octane aircraft gasoline. Manufacturer also claims Tankite is useful as leak preventative in aircraft tanks since it retains its adhesion and flexi-

bility even though immersed in gasoline. (E-40)

Fuel Flowmeter. General Electric's Instrument Department says new in-flight refueling transmitter, called IFR, is designed to measure up to 600,000 lb of fuel per hr compared to 12,000 lb/hr performance of earlier mass fuel flowmeters. 17 lb transmitter can operate at pressures up to 480 lb/sq in. (E-41)

Aircraft Hose Assemblies. Factory preformed Teflon aircraft hose assemblies with -100°F to $+500^{\circ}\text{F}$ ambient temperature range, 1000 psi working pressure and complete inertness to all known oils, fuels and propellants are now available from Resistoflex Corporation. Company reports permanently preforming Fluoroflex-T R3800 hose during manufacture eliminates stress and strain in critical bends. (E-42)

Miniature Bearings. New Departure Division of General Motors Corporation announces complete line of miniature bearings available in wide range of sizes. (E-43)

Altitude Simulator. Westinghouse Electric Corporation says equivalent flight conditions of modern high performance aircraft in altitude variations ranging from -1000 ft to $+80,000\text{ ft}$ are reproduced continuously by new CTI dynamic altitude simulator. Includes control arrangements which permit it to be commanded directly



Potentiometer type transducers for use at temperatures between -60°C . and $+120^{\circ}\text{C}$.

Designs available permit single or multiple range linear output from non-linear input function, and operation over wide ranges of environmental conditions.

Designs available for operation to 160°C .

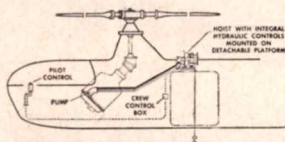
Special instruments for use with corrosive oxidants and fuels are available.

Specifications available on request.

**RAHM
INSTRUMENTS, INC.
12 WEST BROADWAY
NEW YORK 7, N. Y.**

For further information
circle Reader Reply No. 51

from analog computer such as Reeves REAC. (E-44)



Rescue Hoist. New 600 lb capacity personnel rescue hoist assembly based on new packaged design concept developed by Vickers Incorporated includes all controls and special protective devices needed for rescue winch operations. Applicable for all airborne winch installations, although primarily intended for helicopter users. (E-45)

Fasteners. New structural steel bolts, claimed 40 percent stronger, will be put to work for the first time on new F-102A delta-wing jet interceptor by Convair-San Diego, Division of General Dynamics Corporation. Called Hi-Psi, bolts in Convair order are rated at minimum tensile strength of 230,000 psi and minimum shear strength of 130,000 psi. Standard Pressed Steel Company. (E-46)

Aircraft Heater. Les Bowman Engineering Co., is manufacturing portable aircraft heaters to preheat simultaneously engines, battery compartments and pilot cabins of two- or four-engine aircraft. Rated at 250,000 btu/hr, heater is powered by a Kohler K-90 engine which develops 3.6 hp at 3600 rpm. (E-47)

Rotary Actuators. New series of R-4100 26VDC rotary actuators manufactured by Airborne Accessories Corporation are rated at 36 lb/in. maximum and 3 rpm with magnetic brake and adjustable limit switches for up to 120° rotation. Meets specification MIL-A-8064. (E-48)

Shock-Measuring Instrument. Means for counting number of times preselected *g* levels are equalled or exceeded are provided by new Maxson Instruments statistical accelerometer. Originally developed for recording accelerations experienced in the maneuvering of military aircraft or missiles, instrument is useful wherever it is desirable to know what shocks have been encountered. Each channel can be factory-set to count at any level from 2.5 to 10 *g*'s absolute, in increments of 0.5 *g* minimum. (E-49)

Oscillator. Especially suitable for aircraft and guided missile applications, Model 193 rocket tube cavity oscillator, is a co-axial unit that features single control for tuning and uses fixed feed-back. Available for frequencies from 2500 to 4000 mc, with a tuning range of 200 mc/sec. Amerac, Incorporated. (E-50)

Engine and Flight Hour Meters. Engine hour meter records actual operating time of aircraft engine. Installed

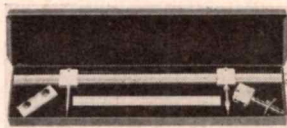
with pressure switch in engine oil line, it starts automatically as oil pressure rises, stops only when engine stops, according to Air Associates, Incorporated. Flight hour meter, installed with an air switch, indicates number of hours aircraft is actually airborne. (E-51)

Self-Sealing Coupling. Self-sealing hydraulic coupling that locks with a simple push and couples against 60 psi in both coupling halves without twisting, turning or special tools is announced by The Weatherhead Company, Aviation Division. Standard fittings and bulk-head flange make coupling adaptable to present and future designs, company reports. (E-52)

Liquid Oxygen Gage. Electronic liquid oxygen quantity gage, using capacitor-type sensing unit in liquid oxygen container, measures and indicates liquid quantity through self-balancing bridge network. Only moving parts are those in motor-driven indicator. For missile applications indicator motor can be used to drive an auxiliary potentiometer instead of a pointer. The Liquidometer Corporation says this would permit telemeter of liquid oxygen or other liquid gas quantity intelligence to the ground, permitting consumption to be determined. (E-53)

Camera Windows. Camera windows maintaining high optical qualities under extreme temperatures experienced in wind tunnel operations and ultrasonic missile work are now available from Corning Glass Works. Made of fused silica, the windows have low index of refraction variation and can withstand temperatures up to 990° C, the company reports. (E-54)

Anti-Rust Compound. International Chemical Company says new anti-rust compound, NoRuSol, protects parts so they can be stored indoors for 30 or more days under normal plant conditions. Can be applied either by spraying or by dipping parts in the solution heated to 130°F. (E-55)



Beam Compass. Product of Engineering Research Associates, Inc., beam compass now features an enlarged set to which has been added a coupling and pen slide. Compass is made of anodized aluminum, satin finish. (E-59)

Hydraulic Components Package for Aircraft. Each package contains two check valves, one depressurizing valve, one by-pass valve, one restrictor, one filter and filter by-pass. Parker Aircraft Company says weight is saved because six housings are eliminated and fewer lines, fittings and mounting provisions are necessary. (E-60)

To the ENGINEER of high ability

AiResearch is looking for your kind of engineer. Through the efforts of engineers like yourself our company has become a leader in many outstanding aircraft accessory fields. Among them are: air-conditioning and pressurization, heat transfer, pneumatic valves and controls, electric and electronic controls, and the rapidly expanding field of small turbomachinery. AiResearch is also applying this engineering skill to the vitally important missile accessory field.

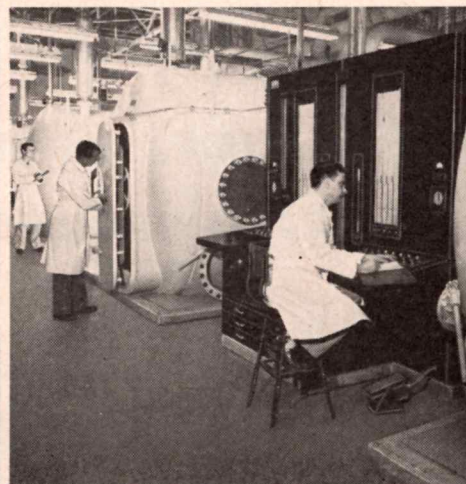
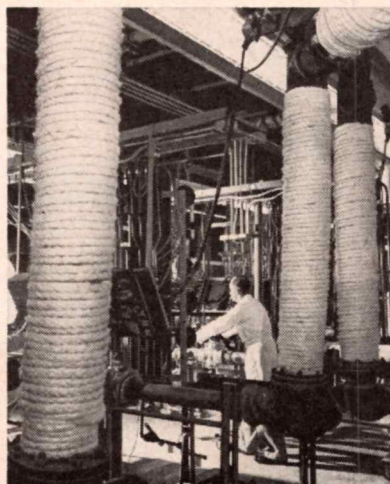
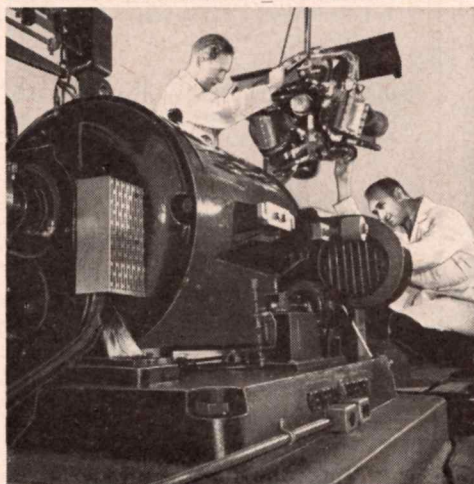
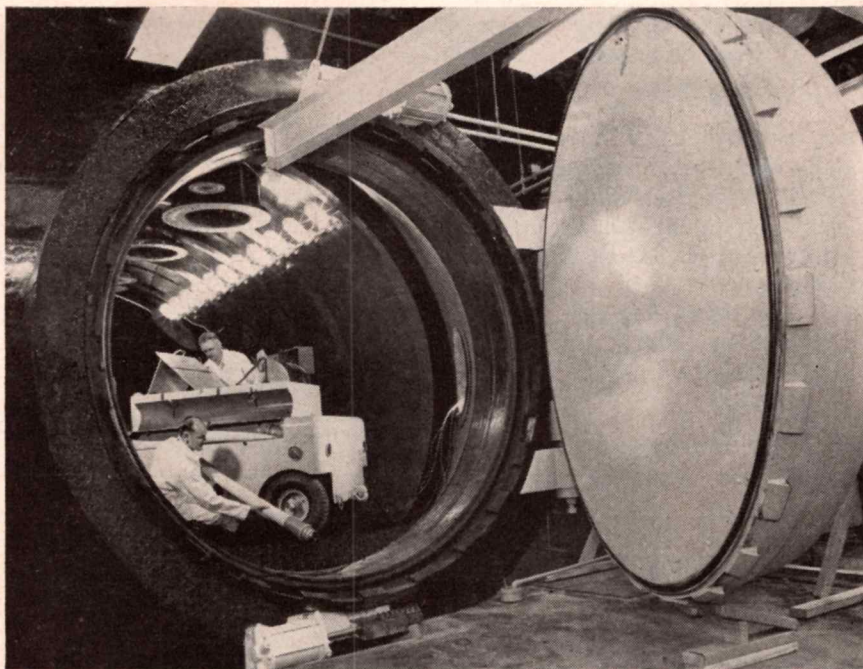
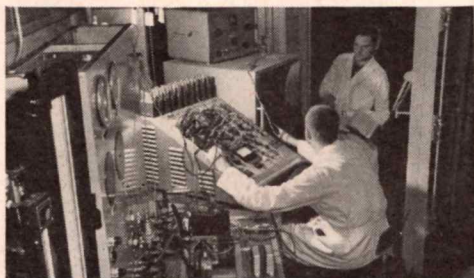
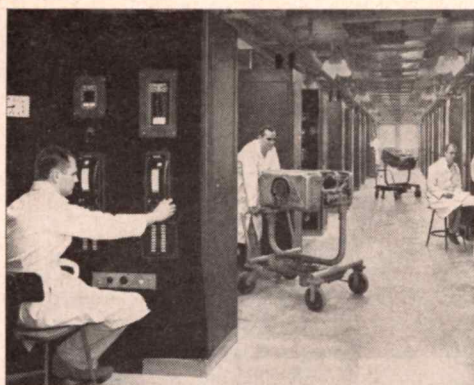
Our engineers work on the very frontiers of present day scientific knowledge. We need your creative talents and offer you the opportunity to progress by making full use of your scientific ability. Positions are now open for aerodynamicists...mechanical engineers...physicists...specialists in engineering mechanics...electrical engineers...electronics engineers.

For further information write today to Mr. Wayne Clifford, THE GARRETT CORPORATION, 9851 S. Sepulveda Blvd., Los Angeles 45, California. Indicate your preference as to location between Los Angeles and Phoenix.

THE GARRETT CORPORATION

AiResearch
Manufacturing
Divisions

For further information circle
Reader Reply No. 71
AERO DIGEST



New AiResearch Production Test Laboratory in Phoenix, Arizona

Finest production test facilities prove aircraft system compatibility

Testing of critical aircraft components and systems is now performed on a precision production basis in these completely equipped laboratories.

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Units tested include gas turbine engines, air turbines, air turbine starters, pneumatic controls, cabin pressure regulators, valves, refrigeration

turbines, heat transfer equipment and complete systems employing these and additional components.

These unsurpassed test facilities are another reason why you can rely on the performance of AiResearch products.

Qualified engineers are needed now. Write for information.



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AiResearch Manufacturing Divisions

Los Angeles 45, California • Phoenix, Arizona

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CABIN AIR COMPRESSORS • TURBINE MOTORS • GAS TURBINE ENGINES • CABIN PRESSURE CONTROLS • HEAT TRANSFER EQUIPMENT • ELECTRO-MECHANICAL EQUIPMENT • ELECTRONIC COMPUTERS AND CONTROLS

For further information circle Reader Reply No. 70

Engineering Editor

for national trade magazine. A.E., M.E., or E.E. degree preferred. Writing ability needed, and some industrial experience desired but not essential. East Coast location. Send resume to Box 1139, AERO DIGEST, 1143 National Press Bldg., Washington, D. C.

calendar

Aug. 1-5—AIR FORCE ASSOCIATION Annual Convention, Roosevelt Hotel and Municipal Auditorium, New Orleans, Louisiana.

Aug. 3-5—EXPERIMENTAL AIRCRAFT Association, 4th Annual Fly-In, Oshkosh, Wisconsin.

Aug. 6-8—Society of AUTOMOTIVE ENGINEERS, National West Coast Meeting, Mark Hopkins Hotel, San Francisco, California.

Aug. 15-17—IAS National TURBINE-POWERED AIR TRANSPORTATION Meeting, Grant Hotel, San Diego, California.

Aug. 19-24—Combustion Institute, 6th International Symposium on COMBUSTION, New Haven, Connecticut.

Aug. 21-24—Western ELECTRONICS Show and Convention, sponsored by IRE and West Coast Electronic Manufacturers Association, Pan-Pacific Auditorium and Ambassador Hotel, Los Angeles, California.

Aug. 22-24—Bendix Scintilla International IGNITION Conference, Sydney, New York.

Aug. 27-31—International Symposium on ELECTRO-MAGNETIC PHENOMENA IN COSMICAL PHYSICS, International Astronomical Union, Stockholm, Sweden.

Sept. 1-3—1956 National AIRCRAFT SHOW, Will Rogers Field, Oklahoma City, Oklahoma.

Sept. 3-9—Society of BRITISH AIRCRAFT CONSTRUCTORS Exhibition and Flying Display, Farnborough, England.

Sept. 10-14—Colloquium on TRANSPORT PHENOMENA IN METALS, International Union of Pure and Applied Physics, Ottawa, Canada.

Sept. 10-14—International Conference on FATIGUE OF METALS, London, England.

Sept. 12-22—INTERNATIONAL AIR RACES, U. S., England, South Africa, starting from Floyd Bennett Field, Brooklyn, New York.

Sept. 17-21—Instrument Society of America, 11th Annual INSTRUMENT - AUTOMATION Conference and Exhibit (International), New York City.

Sept. 17-22—International ASTRONAUTICAL Federation, 7th Annual Congress, Rome, Italy.

Sept. 20-21—Faraday Society General Discussion: The Physical Chemistry of PROCESSES AT HIGH PRESSURES, Glasgow, Scotland.

Sept. 25-29—International Association of Aircraft Constructors, JET TRANSPORT Conference, The Hague, The Netherlands.

Sept. 27-29—Southern California ENGINEERING Conference and Exhibit, San Diego Chapter of Engineers and Architects Association, San Diego, California.

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AERO DIGEST

We'll prove **ON YOUR PARTS**

... a RANSOHOFF Automatic Media Return Tumbling Barrel

SAVES TIME, LABOR, SPACE **ASSURES UNIFORMLY BETTER RESULTS**

widely adaptable for

- CLEANING • DEBURRING
- DESCALING • BURNISHING

Media is retained in drum, eliminating costly hand separation and loss of media.

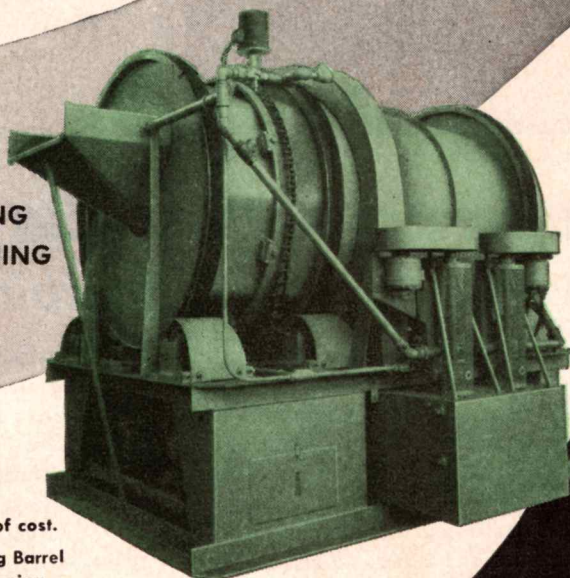
Mass cleaning and finishing of stamped, forged or cast parts in this RANSOHOFF Automatic Tumbling Barrel cuts hours of time and dollars of cost.

The Automatic Media Return Tumbling Barrel performs all operations, including cleaning, deburring, descaling and media separating all within the drum, without manual handling, on an automatic time cycle.

Expertly engineered, compactly designed and ruggedly built, a RANSOHOFF Automatic Media Return Tumbling Barrel may allow mass cleaning and finishing of your parts with tremendous savings in time, labor and cost.

Send samples of your parts for a free evaluation.

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Ransohoff

An old name...the newest ideas

ROLLS-ROYCE TO POWER
AMERICAN BUILT JET AIRLINERS

Trans-Canada Air Lines

have chosen

ROLLS-ROYCE
CONWAY

BY-PASS TURBO JETS

*to power their
Douglas DC-8 airliners*



ROLLS-ROYCE AERO ENGINES LEAD THE WORLD

For further information circle Reader Reply No. 56

Q.E.D.

QUALITY • ECONOMY • DEPENDABILITY



CAMBRIDGE CORPORATION

Creators in Cryogenics • Leaders in Liquid Logistics

The following pages illustrate the production product leaders in the famous Cambridge Corporation line of cryogenics equipment. Every Cambridge-built product, whether custom-tailored or a production unit, bears the Cambridge Q.E.D.—Quality... Economy... Dependability. This is the hallmark which has established Cambridge throughout the Armed Forces and Industry as the Leader in Liquid Logistics.

These product pages are designed to be removed

from this publication and are indexed for your convenience in filing them.

Q.E.D., of course, also means "that which has been demonstrated . . ." Let Cambridge demonstrate what it can furnish you. For a complete brochure, including Cryogenics Ready Reference, encircle #9 on the Reader Reply Card.

A Reader Reply Card number also appears on each of the product pages, so we may furnish to you any additional information or technical service.



CAMBRIDGE CORPORATION

In Lowell, Massachusetts—2 Industrial Park, Glenview 4-7881 • TWX Lowell 432
In Santa Monica, California—920 Santa Monica Boulevard • Exbrook 4-4284



**CAMBRIDGE
CORPORATION**



Model 5S-1

LIQUID OXYGEN CONVERTER

**for
Flight Personnel Breathing Oxygen Systems**



Model 5S-1

LIQUID OXYGEN CONVERTER

Oxygen Breathing Components and Systems

For years, CAMBRIDGE CORPORATION's aircraft breathing oxygen supply dewars have been the standard of excellence in the industry. This same high standard has been built into CAMBRIDGE CORPORATION's advanced

design converters, exemplified by Model 5S-1 shown above. CAMBRIDGE components or complete systems are available, *tailor-made*, to specific engineering and performance requirements.

Model 5S-1 5-Liter Converter

This converter incorporates CAMBRIDGE advanced design concepts of spherical shape, capacitance gauging, high shock and acceleration loadings, and reduced weight and size. Vibration characteristics

have been improved over existing models with no increase in weight or evaporation loss. In fact, Model 5S-1 has broadened every known operational parameter of present day converter design.

SPECIFICATIONS

Capacity:

5 liters at one atmosphere

Weight:

Less than 11 lbs.

Shock Loading:

14 G's in all planes

Acceleration Loading:

Up to 14W in all directions

Evaporation Loss:

Less than 2½ lbs. in 24 hours

Delivery Pressure:

70 psig

Fill Time:

Less than 5 minutes

Pressure Build-Up Time:

Less than 10 minutes

Liquid Level Gauge:

Fixed probe, capacitance type

Temperature Operating Range:

Continuous; from -65° to +160°F

Altitude Operating Range:

From 0 to 60,000 ft.

Flow Rate:

Equivalent to standard gas flow of 60 liters per minute

Alternate Application:

- Available in 8—10—20—25 liter sizes for Cockpit Breathing Oxygen applications.
- Available for Nitrogen Pressurization for missile and aircraft applications.

This product comes with a 1 year warranty against defect in material or labor. Quotation on request.

For further information, encircle #1 on Reader Reply Card.



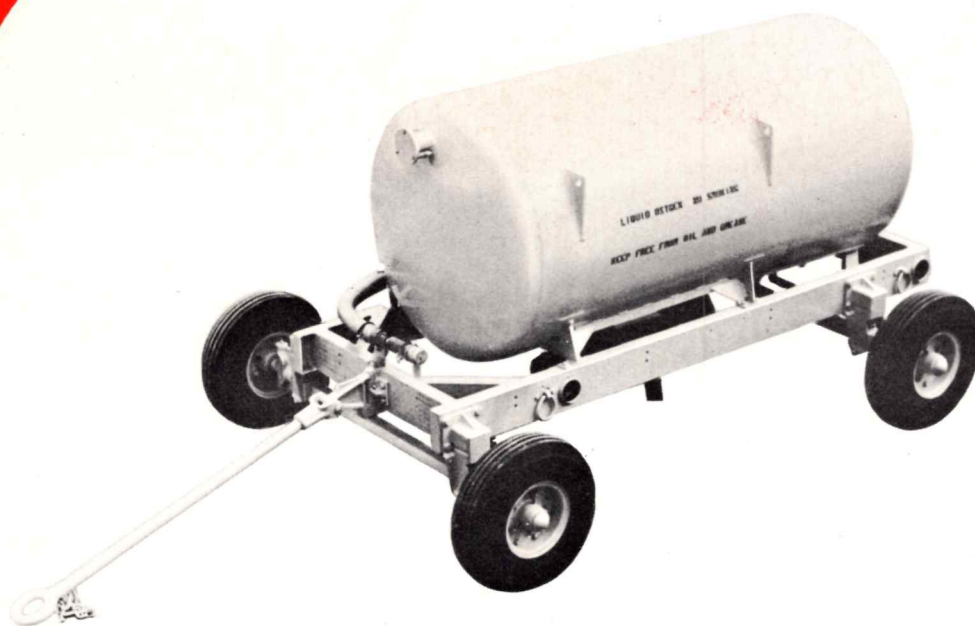
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INDUSTRIAL PARK LOWELL, MASSACHUSETTS • 920 SANTA MONICA BLVD. SANTA MONICA, CALIFORNIA

Creators in Cryogenics • Leaders in Liquid Logistics



**CAMBRIDGE
CORPORATION**



Model CL 50

50 GALLON TRANSPORT DEWAR

50 GALLON
TRANSPORT
DEWAR



Model CL 100

50 GALLON TRANSPORT DEWAR

The CAMBRIDGE Model CL50 LOX Flightline Transport Dewar is designed specifically for use in USAF and US Navy flightline support operations. These units, currently in volume production have been proved in service under various conditions throughout the world. CAMBRIDGE superior vacuum performance is an extremely important reason for the high efficiency of this unit.

The CAMBRIDGE Model CL50 meets and *exceeds* all performance requirements as designated in USAF specifications Mil-T-4796. Model CL50 features rapid pressure build-up time of less than 1 minute and includes safe and simple operational characteristics, low initial cost, and long trouble-free service life. Vacuum leak rate is less than 1×10^{-8} cc/sec and evaporation loss is lower than 2 $\frac{3}{4}$ % per day. Trailer conforms to Mil-T-8299A.

SPECIFICATIONS

Dimensions:

Overall: 104 $\frac{1}{2}$ " long, 67" wide, 54" high
Tow bar — 60"
Outer Shell: 60" long, 36 $\frac{1}{4}$ " diam.
Inner Shell: 45-1 $\frac{5}{8}$ " long, 20 $\frac{1}{4}$ " diam.

Shipping Weight:

1200 lbs.

Capacity:

Liquid O₂ or N₂ 50 gallons
Water Volume 55 gallons

Materials:

Outer Shell: $\frac{1}{8}$ " 5052 Aluminum
Inner Shell: $\frac{3}{32}$ " 5052 Aluminum
Insulation: Powder-Vacuum

Mil Spec. Conformed to:

Mil-T-4796 and to Navy Bureau of Aeronautics
Mil-T-4829 modification
Mil-T-8299A (Trailer)

Operating Characteristics:

Evaporation Loss: less than 2.75% per day
Operating Pressure: 50 psig (USAF MA-1)
100 psig (USN No. 4)
Vacuum Loss Rate: less than 1×10^{-8} cc/sec
Pressure Build-up Time: less than 1 minute @ 50 psi
less than 2 minutes
@ 100 psi

Safety Devices:

Cambridge safety valve No. A241, rupture disc,
Cambridge 80-90 psig safety head, Cambridge relief
valve No. A225.

System Components and Controls:

Pressurizing Coil under dewar; pressure build-up control valve; fill, discharge and vacuum valves; Cambridge vacuum filter, vacuum and pressure gauges, liquid level gauge.

Alternate Application:

- Available for use with Liquid Nitrogen, Argon, and Hydrogen (with or without Nitrogen Shield).
- Available: As Nitrogen Pressurization cart with 3000 psi pumping capability.

This product comes with a 1 year warranty against defect in material or labor. Quotation on request.

For further information, encircle #2 on Reader Reply Card.



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**CAMBRIDGE
CORPORATION**



Model 2500

LIQUID OXYGEN STORAGE DEWARS

LOX
STORAGE
DEWARS



Model 500L

LIQUID OXYGEN STORAGE DEWARs

The CAMBRIDGE line of storage dewars is available in series from 150 to 15000 gallons liquid capacity. These Dewars are designed to store bulk quantities of Liquid Oxygen, Liquid Nitrogen, Liquid Argon or Hydrogen for long periods at extremely low loss. The advanced trend of CAMBRIDGE CORPORATION's cryogenic "know-how" is reflected in the high performance characteristics of these outstanding storage units. The Model #2500 is enjoying wide acceptance in industry, as an efficient, low cost customer bulk station, and as a rugged, dependable component in the liquid logistics program of the Armed Forces.

SPECIFICATIONS Model 2500

Dimensions:

Overall: 235 $\frac{7}{8}$ " long, 95" wide, 111" high
Outer Shell: 194 $\frac{7}{8}$ " long, 84" diam.
Inner Shell: 178 $\frac{3}{8}$ " long, 66" diam.

Shipping Weight:

from 16,000 lbs.

Capacity of 2160 gal. size:

Liquid O₂ or N₂ : 2160 gallons
Water Volume: 2484 gallons

Materials:

Outer Shell: 5/16" Carbon Steel
Inner Shell: 3/16" 304 Stainless
Insulation: Powder-Vacuum

Optional Equipment:

These storage Dewars rarely require pumping down. However, a vacuum pump and vacuum pump oil trap are offered as optional equipment for those installations where suitable vacuum pumping equipment is not available.

CAMBRIDGE Bulk Storage Dewars feature extremely low evaporation loss as exemplified in model 500L at approximately 1.2% per day. Model 2500 offers $\frac{1}{2}$ % per day and in larger sizes evaporation drops to less than $\frac{1}{4}$ % per day. Another important factor is the quick pressurization which assures adequate suction pressures to facilitate transfer operation at flow rates as high as 250 GPM.

This Hi-Fidelity vacuum performance insures minimum service requirements and long trouble-free life.

Operating Characteristics:

Evaporation Loss: less than $\frac{1}{2}$ % per day
Operating Pressure: 60 psig
Pressure Build-up Time: 2-10 minutes.

Safety Devices:

Cambridge Spec. A241 safety valves, rupture disc, Cambridge safety head.

System Components and Controls:

Cambridge 2510-2 vacuum filter, vacuum gauge, vacuum valve, air release valve. Unit skid mounted. All piping and equipment enclosed in steel head forming part of outer shell.

Alternate Application:

- Available as cold converter customer station with operating pressure to 300 psi.
- Also available for use with Argon or Liquid Hydrogen with or without Nitrogen Shield.
- Specifications of other models on request.

This product comes with a 1 year warranty against defect in material or labor. Quotation on request.

For further information, encircle #3 on Reader Reply Card.



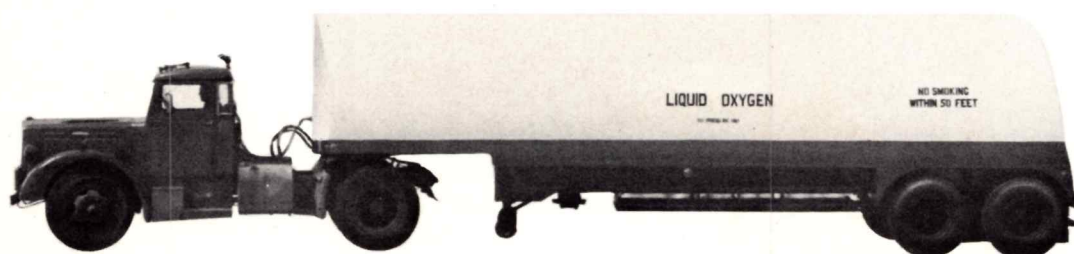
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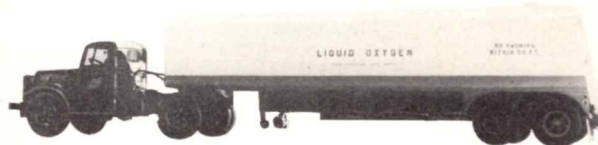
**CAMBRIDGE
CORPORATION**



Model 2700

3600 GALLON TRANSPORT DEWAR

3600 GALLON
TRANSPORT
DEWAR



Model 2720

4000 GALLON TRANSPORT DEWAR

The CAMBRIDGE Model 2700-3600 gallon Liquid Oxygen/Nitrogen Trailer is an outstanding example of quality engineering and manufacture. Its performance has exceeded design expectations in all categories and it is today in volume production for both the Armed Forces and industry. The CAMBRIDGE Model 2700 has achieved universal recognition as the TOP performer in its class.

Rugged Roadability: The Model 2700 is performing today under severe extremes of climate over adverse road conditions; through deep mud, sun-scorched ruts, slush, snow and jarring frost heaves. It will come to a smooth stop from 40 MPH in less than 100 feet. Its low center of gravity will permit it to negotiate a 75 ft. radius curve at 25 MPH.

Cryogenic Excellence: Evaporation losses under $\frac{1}{2}\%$ per day. Hi-fidelity vacuum performance which practically eliminates the need for pumping down. Quick pressure build-up which *can be maintained during transfer operations.*

Safe, Efficient Design: Compartment specifically designed for simple and safe operation. Fully equipped with functional safety devices. Meets all ICC requirements and regulations.

SPECIFICATIONS Model 3600

Dimensions:

Overall: 33½' long, 10½' high, 8' wide
C of G: 6'2" off road

Weight:

Empty: 24,500 lbs.
Loaded: 60,000 lbs.

Capacity:

Liquid O₂: 3600 gallons
Water Volume: 3780 gallons

Materials:

Outer Shell: Carbon Steel
Inner Shell: 304 Stainless Steel
Insulation: Powder-Vacuum

Operating Characteristics:

Evaporation Loss: less than $\frac{1}{2}\%$ per day
Operating Pressure: 25 psig.

Safety Devices:

Outer Shell: standard Cambridge safety head.
Inner Shell: 2" Teflon seated pop safety valve set for 30 psig; 2" bursting disc safety head set for 35 to 40 psig.

System Components and Controls:

250 GPM transfer pump, Cambridge Model 2510 vacuum filter, vacuum and pressure gauges, 1½" neoprene diaphragm type vacuum valve, extended stem fill and discharge valves and vacuum pressure relief valve. Quick pressurizing coil mounted under trailer. Liquid line protected with ½" Teflon seated pop safety valve, set at 100 psig. Pump, valves and gauges mounted in sheet steel compartment forming an extension of outer shell. Transfer Hose Safety Valves—Liquid Level Gauge. Interior Lighting available as well as flow metering equipment at extra cost.

Alternate Application:

- Available for use with Argon or Liquid Hydrogen with or without Nitrogen Shield.
- Available in 2000 gal. size with 3000 psi pumping equipment for bottle filling.

This product comes with a 1 year warranty against defect in material or labor. Quotation on request.

For further information, encircle #4 on Reader Reply Card.



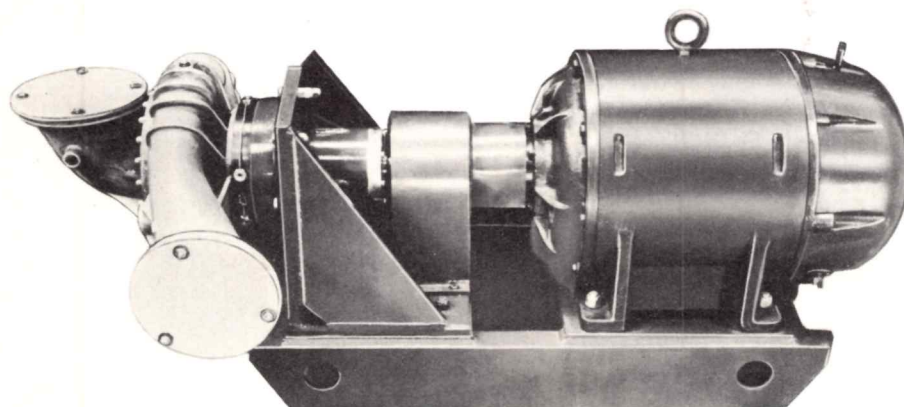
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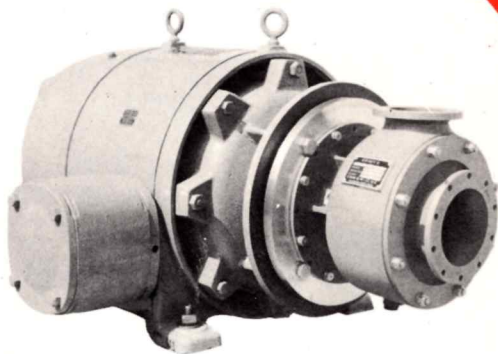
**CAMBRIDGE
CORPORATION**



Model EL 1000

LIQUID OXYGEN PUMP

**LIQUID
OXYGEN
PUMP**



Model EL 6100

LIQUID OXYGEN PUMP

As Designed and Built by J. C. Carter Co.,
Costa Mesa, Calif.

LIQUID OXYGEN TRANSFER AND PRESSURIZING PUMPS

CAMBRIDGE CORPORATION has long recognized an urgent need for liquid oxygen pumping equipment of extremely high capacity and trouble-free operating characteristics. To meet this demand, CAMBRIDGE CORPORATION offers a line of liquid oxygen pumps, unmatched in industry today and

service-proved in our own advanced 60,000 GPH liquid oxygen test loop now in operation at Lowell, Mass. CAMBRIDGE LOX transfer pumps require no cool down prior to operation, an important feature reducing losses incurred during transfer operation.

SPECIFICATIONS

Model EL-1000

There is no other pump today which is capable of approaching CAMBRIDGE CORPORATION'S Model EL-1000; capacity up to 1000 GPM of liquid oxygen, at heads up to 500 feet and relatively low NPSH.

Typical Performance Data at 3570 RPM

Capacity: 800 GPM
Head: 500 feet
Required NPSH: 16 feet
Power Requirement: 150 HP

Weight of Pump:

Under 100 lbs.

Type:

Centrifugal, volute casing

Materials:

Aluminum 356-T6

Model EL-6100

The CAMBRIDGE Model EL-6100 is a lightweight liquid oxygen pump with a small space envelope, capable of transferring 250 GPM at 133 ft. head. Requires no cool down and is available with variable speed features achieving flow rates of 10 GPM to 250 GPM.

Typical Performance Data at 3570 RPM

Capacity: 250 GPM
Head: 133 feet
Required NPSH: 16 feet
Power Requirements: 15 HP

Weight of Pump:

Approx. 16 lbs.

Type:

Diffuser type, Centrifugal

Materials:

Aluminum 356-T6

Model EH-3000 HIGH PRESSURE PUMP

Model EH 3000 is an immersion type, reciprocating pump capable of pressurizing 120 gallons per hour of liquid oxygen (equivalent to 12,000 cubic feet of gas) to 3500 psi. Modifications of this unit are available to suit particular pressure and capacity requirements.

All CAMBRIDGE pumps are given severe cycling tests in our test loop. CAMBRIDGE CORPORATION'S unique liquid oxygen test facilities and pump engineering experience are combined today in the production of *complete transfer systems* of unparalleled excellence.

This product comes with a 1 year warranty against defect in material or labor. Quotation on request.

For further information, encircle #5 on Reader Reply Card.



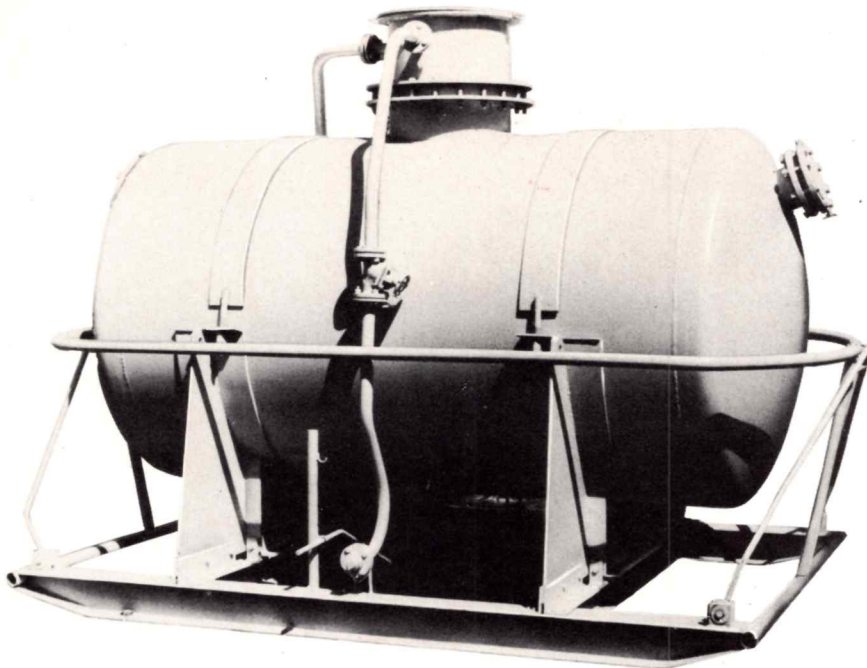
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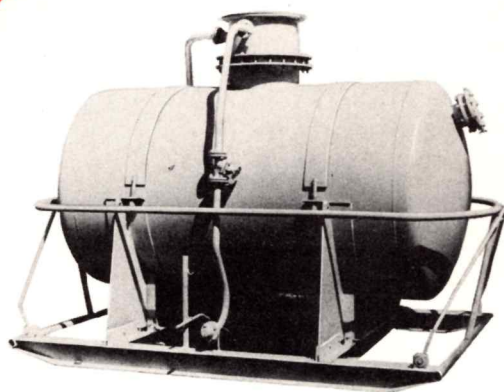
**CAMBRIDGE
CORPORATION**



Model 2310

HYDROGEN PEROXIDE TANKS

HYDROGEN
PEROXIDE
TANKS



Model 2310

HYDROGEN PEROXIDE TANKS

CAMBRIDGE CORPORATION manufactures a wide variety of Hydrogen Peroxide Storage Tanks and Trailers. Our superb weldments

are a contributing factor to the high degree of acceptance these units are enjoying in industry today.

SPECIFICATIONS

Model 2310

Dimensions:

Overall: 96" high, 120" long, 84" wide
Tank: 60" diam. x 117.75" long

Weight:

Empty: 4,000 lbs.
Loaded: 16,000 lbs.

Capacity:

Water Volume: 1300 gallons

Materials:

3/8" thick passivated 5652 aluminum

Safety Devices:

Permanent vent, quick opening dump valve; high temperature warning alarm

Construction:

Tank 3/8" thick passivated 5652 aluminum plate. Carbon steel saddles clamped on by steel straps; saddles bolted to carbon steel skid.

Alternate Applications:

Trailers for transport of Hydrogen Peroxide available in 2000 and 3000 gal. capacity built of 5652 Aluminum. Also available in various sizes for use as process tanks.

Quotation on request.

For further information, encircle #6 on Reader Reply Card.



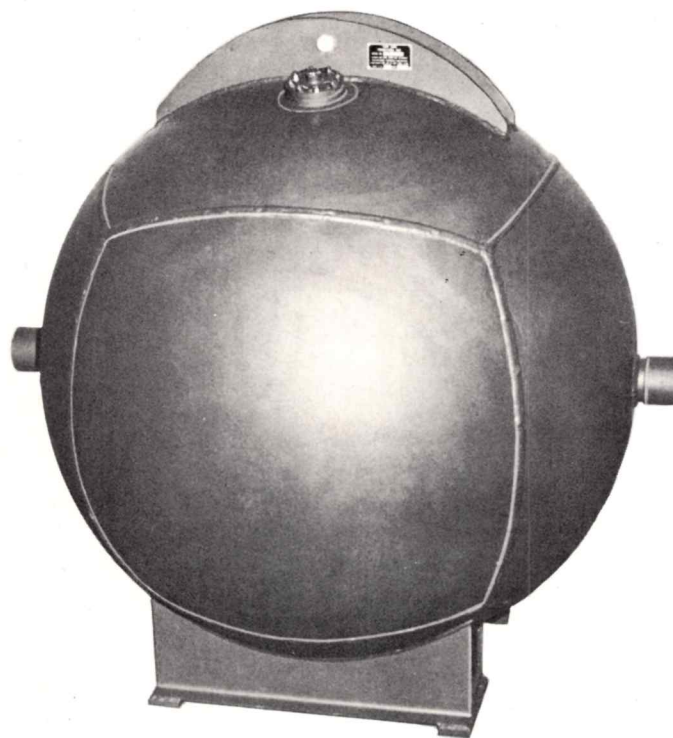
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**CAMBRIDGE
CORPORATION**



Model N-61

**RED FUMING
NITRIC ACID TANKS**

**NITRIC
ACID
TANKS**



Model NA-66*

RED FUMING NITRIC ACID TANKS

CAMBRIDGE CORPORATION manufactures a wide range of tanks and trailers for the storage and transportation of red fuming nitric acid, fluorine, and similar corrosive materials. The photo on other side is CAMBRIDGE Model N-61, 380 gallon spherical nitric acid tank designed specifically for the storage and transfer of this material when used as an oxidizer in propulsion units.

Model N-61 is fabricated with extreme care and skill from 6061-T4 $\frac{3}{8}$ " aluminum sheet. It is an outstanding example of the advanced welding capability which has made CAMBRIDGE CORPORATION a leader in the field of difficult and creative manufacture.

*Present production techniques make these tanks available fabricated from two hemispheres thereby eliminating extensive welds and reducing possibilities of leakage. (Note model NA-66 above.)

SPECIFICATIONS

Dimensions:

Tank: $56\frac{1}{4}$ " diam-spherical
Overall, on skid: $63\frac{1}{2}$ " high, $61\frac{3}{4}$ " wide

Shipping Weight:

4000 lbs.

Capacity:

380 gallons

Working Pressure:

200 psig

Material:

6061-T4, $\frac{3}{8}$ " aluminum sheet

Alternate Uses:

Missile fueling and transport application utilizes a trailerized modification which simplifies handling.

This product comes with a 1 year warranty against defect in material or labor. Quotation on request.

For further information, encircle #7 on Reader Reply Card



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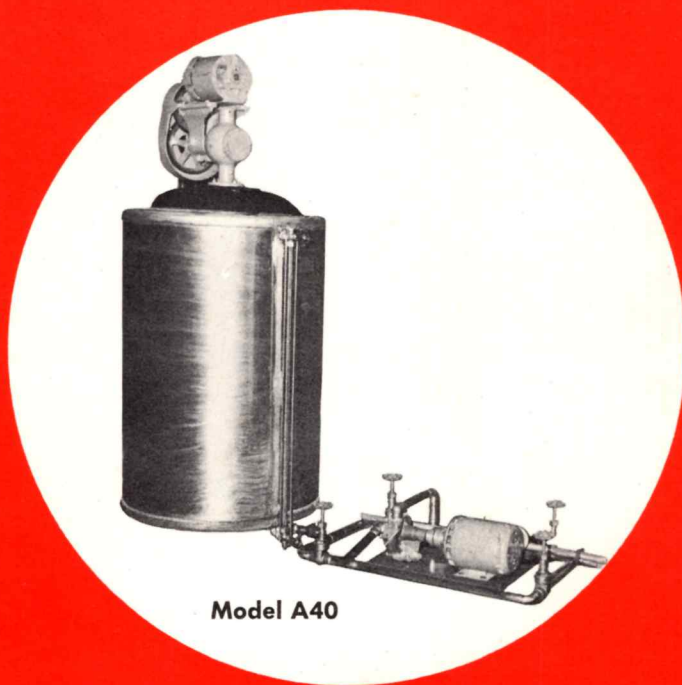
**CAMBRIDGE
CORPORATION**

Model B



ANILINE TANKS

ANILINE -
L. P. GAS
TANKS



Model A40

ALCOHOL PROCESS UNIT

CAMBRIDGE Aniline Tanks are available in a wide variety of designs and capacities. Photo on reverse side is CAMBRIDGE Model B 250 gallon aniline tank which is currently being manufactured in production quantities for the Armed Forces and industry.

These units are precisely manufactured to rigid specifications and meet the exacting requirements inherent to the safe storage and transportation of hard-to-handle liquids.

The Model A-40 Alcohol Process Unit shown above is representative of the diverse manufacturing capability offered by CAMBRIDGE for products best suited to the expeditious handling, transfer or storage of fuels and oxidizers.

SPECIFICATIONS

Model B Aniline Tank

Dimensions:

Tank: 70 $\frac{3}{4}$ " long, 37 $\frac{5}{8}$ " diam. on center line, 32 $\frac{1}{4}$ " diam. at head
Overall: 77 $\frac{1}{4}$ " long, 43" diam.

Shipping Weight:

675 lbs.

Capacity:

250 gallons

Working Pressure:

50 psig

Materials:

12 gauge
1020 steel, electric arc welded joints and seams

Alternate Uses:

As modified for use with LP gas at 300 psi.

This product comes with a 1 year warranty against defect in material or labor. Quotation on request.

For further information, encircle #8 on Reader Reply Card.



CAMBRIDGE CORPORATION

INDUSTRIAL PARK LOWELL, MASSACHUSETTS • 920 SANTA MONICA BLVD. SANTA MONICA, CALIFORNIA

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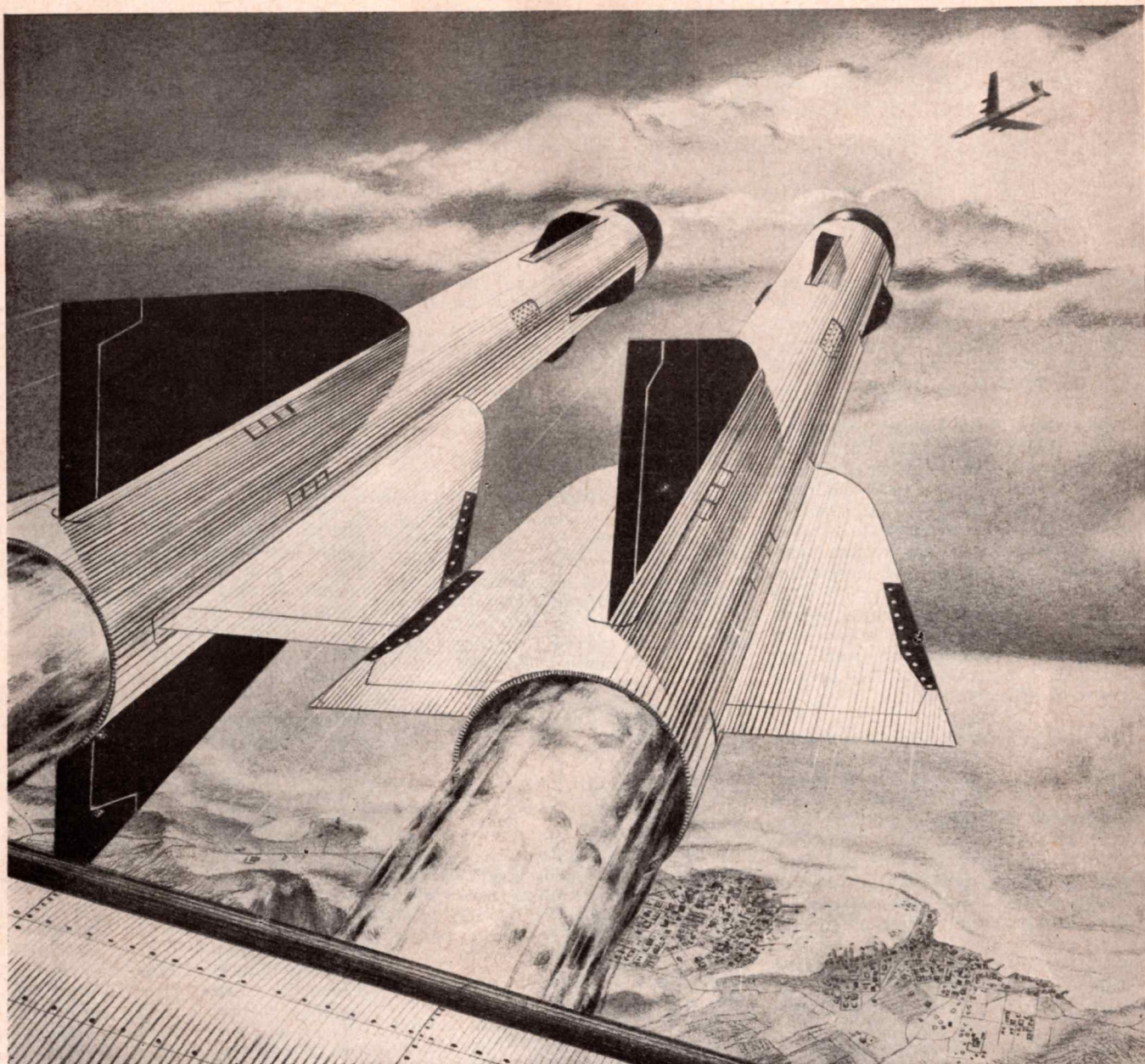
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For further information circle Reader Reply No. 59

SOLAR
AIRCRAFT COMPANY



Designers, developers and manufacturers of gas turbines—
aircraft and missile components—bellows—controls—high
temperature coatings—metal alloy products

trade literature

You may obtain copies of booklets and pamphlets below by circling the appropriate number on the Reader Reply Card on page 113.

Plant Facilities. 12 pp brochure describes technical and production capabilities of Longren Aircraft Company, specialists in solving machine design, metal forming and reinforced plastics problems in aircraft. (T-1)

Alloy Sheet Metal Fabrication. 30 pp illus booklet, "Guide for Purchasing Complex and Unusual Alloy Sheet and Light Plate Fabrication," describes how special fabrication skills solved problems involving intricate shapes, close tolerances, special welding techniques, high finishes and mechanical components. Alloys include stainless steel, aluminum, monel, inconel, nickel, titanium and other metals in gages up to $\frac{3}{8}$ in. Sizes vary from small assemblies to dimensions of 30 ft long or more. S. Blickman, Inc. (T-2)

Jet Engine Fuel System Components. 88 pp illus Chandler-Evans product guide describes and gives specifications of main fuel regulators and controls, emergency controls, afterburner controls and hydraulic valves. Complete data is also given on vane and gear type pumps, as well as carburetors and Protek-Plugs. Book features numerous diagrams and tables. (T-3)

Pocket-Size Table of Gas Boiling Points. Gives boiling point of 20 gases at 1 atmosphere on Centigrade, Fahrenheit, Kelvin and Rankin scales. Handy plastic table also lists equivalent values of one liter and one gallon of liquefied gas. Cambridge Corporation. (T-4)

Leak Detector. 8 pp illus brochure, GEC-233F, describes features, applications, specifications and operation of a General Electric portable instrument, Type H-1, for locating leaks in closed systems. (T-5)

Investment Casting. 40 pp illus booklet contains data to show how process can be used to best advantage. Section on design outlines strong points and commercial limitations of production method. A complete description of the alloys used in producing Haynes investment castings, such as cobalt and nickel-base alloys; stainless, low alloy and carbon steels. Physical, mechanical and chemical properties are included. Haynes Stellite Company. (T-6)

Production Service. 16 pp profusely illus booklet presents the engineering and production facilities of the Cam-

bridge Corporation, the resultant products and their applications. (T-7)

Printed Circuitry. 4 pp brochure outlines Croname Incorporated's facilities for producing printed circuits and offers recommendations on the basic steps necessary for exact circuit duplication. (T-8)

Shock and Vibration Mount. Bulletin No. 56-01 gives complete engineering application data, performance curves and construction details of Barry Controls Incorporated new MIL-size 1 All Angl shock and vibration mount, especially designed to give low transmissibility in natural frequency range for jets and missiles. Includes series of six transmissibility curves showing all attitude performance from horizontal through bulkhead-mounted positions. (T-9)

Welding of Steel Castings. 40 pp manual published by the Steel Founders Society of America gives recommended welding procedures for carbon-steel and low-alloy steel castings. Section on electrodes lists trade names and manufacturers for all classes of electrodes. Tempil Corporation (T-10)

Profilometer. 14 pp illus catalog 156 covers equipment for manual operation, straight-line mechanical tracing and circular tracing, in addition to equipment for recording the microinch roughness readings. Micrometrical Manufacturing Company. (T-11)

Metal-Ceramic Receiving Tubes. 20 pp illus booklet ETD-1212-A discusses design and construction innovations of General Electric's micro-miniature metal-ceramic receiving tubes and gives application data, operating characteristics and construction features. (T-12)

Stainless Pipe. 8 pp technical folder TB-410 deals with the use of seamless and welded stainless steel pipe and stainless steel welding fittings where corrosion and/or elevated temperatures are determining factors. Contains application data on the most widely used stainless steels and furnishes helpful hints on the bending, joining and welding of these products. Tubular Products Division of the Babcock & Wilcox Company. (T-13)

Control for Aerodynamic Testing. 20 pp illus booklet MSP-133 describes

Hagan Corporation's line of electrical and electronic automatic control equipment designed for use in aeronautical testing. Typical applications include control of surge, altitude and mass flow in all types of wind tunnels. Includes descriptions of each device's function, method of operation and specifications. (T-14)

Machine Tool Electrical Standards. 44 pp revised manual issued by National Machine Tool Builders' Association contains great deal of additional data, much of it in tabular form. Discusses motor and circuit protection, control circuits and circuit enclosures and specifications for conductors. Includes new 4 page glossary of electrical terms. (T-15)

Adhesive Bonding. 8 pp illus booklet describes application techniques and precautions, advantages and limitations of adhesive bonding at room temperature, with emphasis on new epoxy based adhesives which need neither heat cure nor pressure. Includes tables and charts. Rubber & Asbestos Corp. (T-16)

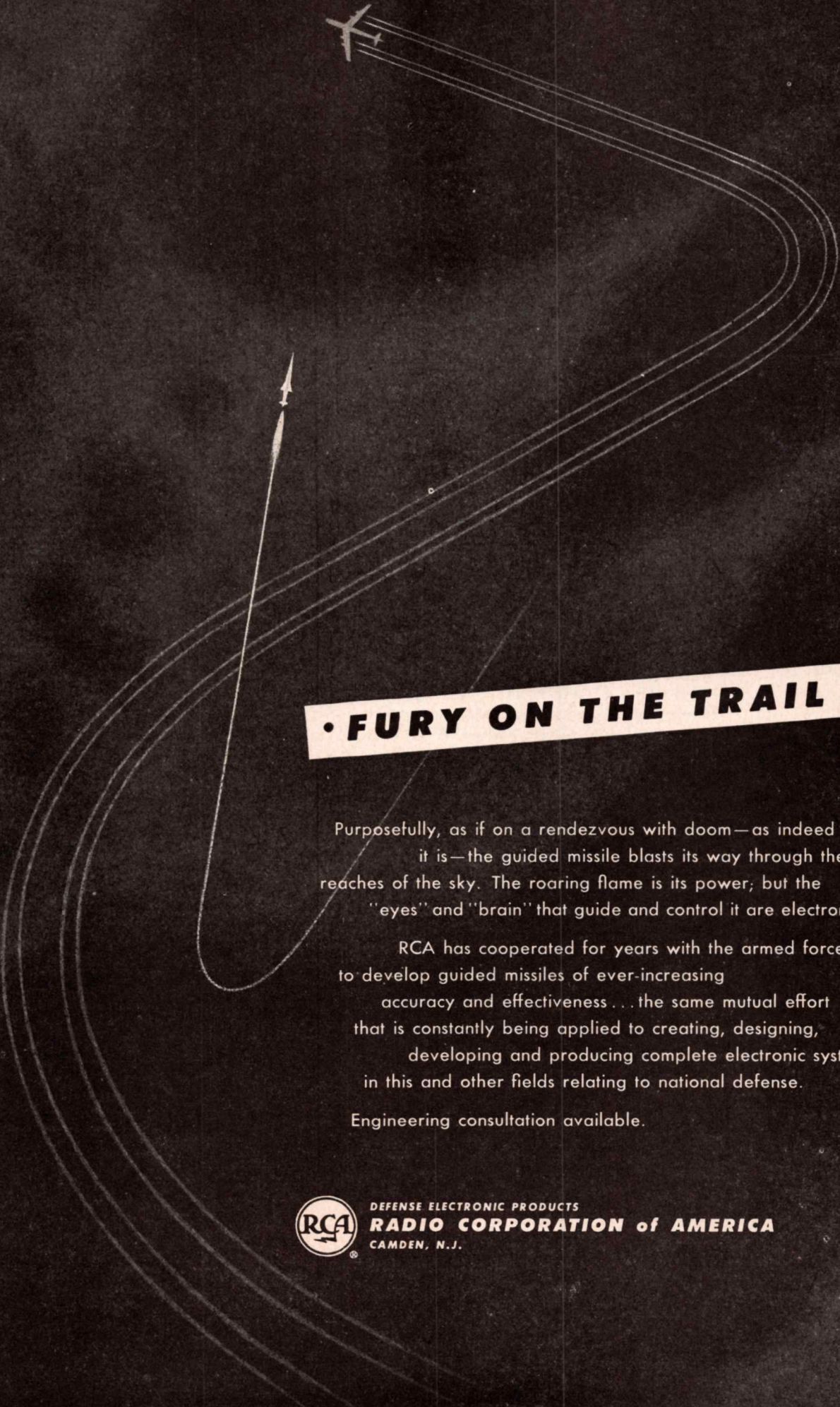
Mechanical Seals. 8 pp illustrated technical bulletin S-205-2 describes complete line of Crane Paking Co. chemically inert mechanical seals for handling all types acids, corrosives, solvents and gases. Provides construction, service and application information, including representative installations and engineering details. Can be used in temperatures from -120°F to $+500^{\circ}\text{F}$ and pressures to 750 psi. (T-17)

Mobile Electronic Laboratory. Newsletter No. 1, Vol. 7, issued by the Electronics Systems Division of Cook Electric Company, illustrates and describes the mobile electronics laboratory that was custom engineered and equipped for the Airborne Instrumentation Section of the Instrumentation and Standards Branch, Electro Mechanical Laboratory of the Army at White Sands Proving Ground to be used at remote missile test sites. (T-18)

Reversible Plug Gages. 4 pp folder describes Pratt & Whitney Company's line of reversible plug gages and includes tabular presentation of standard sizes and specifications. (T-19)

Refractory Molybdenum Borides. 6 pp bulletin Cdb-8 discusses applications, properties and preparation of

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• FURY ON THE TRAIL

Purposefully, as if on a rendezvous with doom—as indeed it is—the guided missile blasts its way through the long reaches of the sky. The roaring flame is its power; but the "eyes" and "brain" that guide and control it are electronics.

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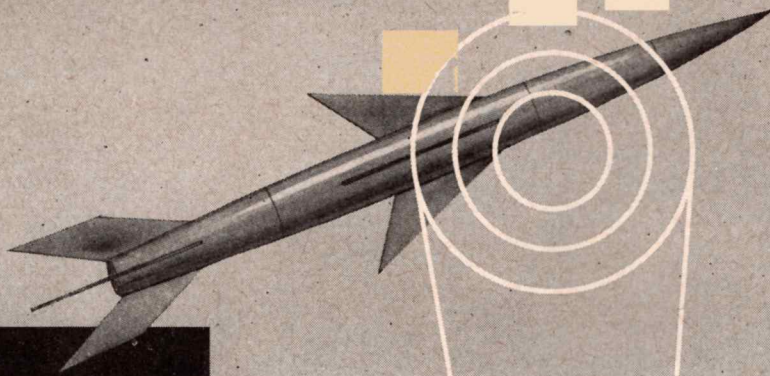
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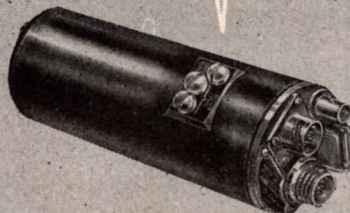
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Now, as through the years, Radio Receptor, a leading contractor to the Armed Forces and Industry for almost 35 years, contributes heavily to America's conquest of the skies . . . by designing . . . and producing a wide range of radio aids to navigation for both piloted and unmanned aircraft.

To this field, Radio Receptor has introduced such developments as the AN/CRN-11 Air Transportable Radio Range; the first airborne and ground VHF equipment used by CAA; omnidirectional radio range systems in low and medium frequencies with associated airborne receivers . . . and the BC-446 transmitter which was the corner-stone of radio range navigation for AACS. The recent S-Band Missile Beacon illustrated and briefly described below is another example of the dynamic role Radio Receptor plays in the national defense.

One of RRco.'s latest projects is the design, development and manufacture of the subminiature S-Band Missile Beacon for the Army. This transistorized unit 6" long by 2½" in diameter provides communication facilities which permit tracking and guidance of the missile in flight.



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For further information circle Reader Reply No. 50

molybdenum boride compounds. Present and potential applications include cutting tools, refractory cermets for use in jets and rockets, parts subject to abrasion and corrosion, and brazes. Climax Molybdenum Company. (T-20)

Synthetic Rubber Jet Aircraft Pavement. 8 pp illus booklet describes use of synthetic rubber, blended with tar, to protect airfield pavements from the deteriorating effects of jet fuel spillage. United States Rubber Co. (T-21)

Disogrin. Brochure discusses disogrin, new diisocyanate polyester elastomer produced by Greer Industries, Inc., who claim it offers unusually high tensile strength, extreme abrasion resistance, as well as resistance to high ozone concentrations, oil and jet fuels and radio-activity. (T-22)

Analog Computers. 16 pp illus catalog describes complete line of Philbrick electronic analog computers, including K3 Series of analog computing components for rapid set-up of problem where operator has minimum knowledge of electronic circuitry. George A. Philbrick Researches, Inc. (T-23)

HET Anhydride. 17 pp bulletin No. 43 relates chemical's properties as a hardener or curing agent for liquid epoxy resins and gives properties, typical reactions and suggested uses. Hooker Electrochemical Company. (T-24)

Alloy Applications. Folder lists 63 known applications—most of them in the metal-working field—for Cerro de Pasco Corporation's group of low-temperature-melting alloys. (T-25)

Sub-Miniature Connectors. 8 pp illus bulletin D-6 gives dimensional data; soldering, mounting and shell deviations; and standard assemblies and variations of Cannon Electric's Type "D" sub-miniature connectors. (T-26)

Metalworking Machines. 44 pp illus catalog presents complete line of Di-Acro metalworking machines which perform a wide variety of forming, cutting, punching and notching operations in medium and light weight materials, according to O'Neil-Irwin Mfg. Company. (T-27)

Air Deflecting Fence. 8 pp illus brochure shows how Boeing Airplane Company and Blackstone Manufacturing Company have solved the critical problem of damaging air blasts from jet engines, propellers and atmospheric disturbances by the development of a vane type air deflecting fence which turns the wind upward

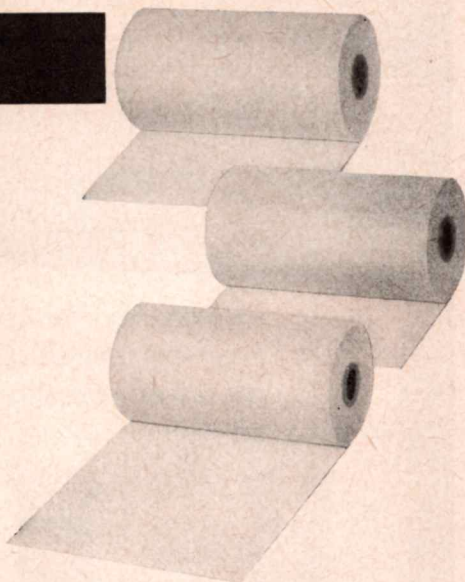
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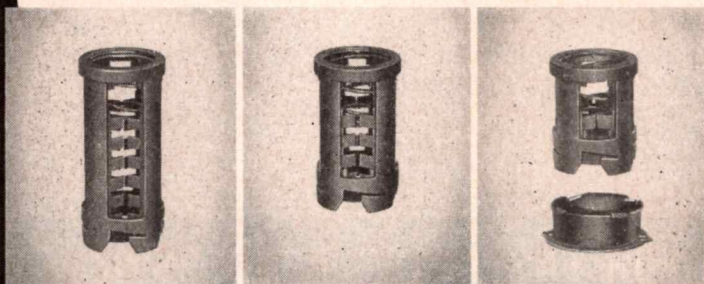
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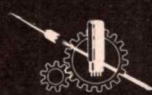
Improve your equipment reliability—specify IERC "B" type shields to end premature tube failures caused by heat and vibration effects.

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For further information circle Reader Reply No. 32

where it can do no damage. Includes plans and specifications. (T-28)

Aluminum. New edition of folder, "How to Use and Apply Alloys and Fluxes for Soldering, Brazing and Welding Aluminum and Aluminum Alloys," includes tables which show for typical aluminums the old and new type designations, melt and flow temperatures, plastic ranges and strengths. All-State Welding Alloys Co., Inc. (T-29)

Wire Wound Resistors. 12 pp illus bulletin C-1a covers tubular and flat power wire wound resistors made by International Resistance Company. Gives data on construction, features, types, rating, terminations and leads and coating. Includes detailed charts and graphs. (T-30)

Metal Fabrication. 34 pp booklet illustrates small metal components and assemblies of parts, as well as the machines that make them. Relates case histories in which The Risdon Manufacturing Company engineers have redesigned components previously made in two or three parts by reduction to one complete unit. (T-31)

New Industrial Material. Brochure discusses entirely new type of industrial material which has been designated "60 Case." This designation covers long, round, hardened bars for use as guide rods, shafts, rolls, piston rods and axles. Material is AISI 1060 Steel which has a surface hardness close to 60 on the Rockwell C scale and is precision ground to standard diameters. Thomson Industries, Inc. (T-32)

Potentiometer. 4 pp bulletin A-3 presents data on new 2-w rheostat potentiometer, known as Type 2W. Variable wire wound control provides maximum adaptability to meet rheostat and potentiometer applications within its power rating, according to manufacturer, International Resistance Co. (T-33)

Aerolog Performance Computers. 8 pp pamphlet thoroughly describes new computer series, designated Model 211 Aerolog Computer, which has been designed specifically to meet the requirements of aircraft industries which are interested in determining aircraft range and fuel consumption as well as computing steady-state rates of climb, maximum speeds, lift coefficients and climb angles. Link Aviation, Inc. (T-34)

Sampler of Rubber and Plastic Lining Compounds. Folder carrying 11 actual specimens of rubber and elastomeric materials represents standard compounds used in the majority of corrosion and abrasion resistant lining work performed by Automotive Rubber Company engineers and technicians on vessels, pipe, fittings, duct work and fans. (T-35)

Rod End Bearings. Brochure covers completely new series of rod end con-

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key to the
battlefields
of the future



U. S. Army Photo

This is one of a series of ads on the technical activities of the Department of Defense.

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JULY 1956

● One of eight permanent Ordnance Corps arsenals, Redstone is the center for the Army's rocket and guided missile program. Its 40,000 acres are located on the Tennessee River near Huntsville, Ala., and house research laboratories, environmental test equipment and several rocket-testing ranges. Redstone Arsenal's military and civilian scientists and engineers produce weapons ranging from a tiny training rocket to the giant IRBM, now being developed on a crash basis by the recently-established Army Ballistic Missile Agency.

From the research, development, production and field service headquarters located at Redstone flow thousands of directives covering the rocket and guided missile work being done by research laboratories, universities and private industry throughout the nation. Weapons systems developed by this Ordnance-Industry team include the Super Bazooka infantry rocket, the Honest John artillery rocket, the Corporal missile and the Nike anti-aircraft missile.

Scientific barriers of all kinds are being broken by the 9,000 employees of Redstone Arsenal, but the exciting and difficult technology of guided missile development constantly presents new problems. Electronic computers click away at missile trajectory formulas by day, while at night rockets equipped with headlights streak down-range, adding valuable data to our country's newest arsenal of defense.

REDSTONE BALLISTIC MISSILE — This long-range rocket-powered, bombardment weapon was developed by the arsenal's guided missile team headed by Dr. Wernher von Braun. The Redstone is the progenitor of the Army's IRBM, the Jupiter.

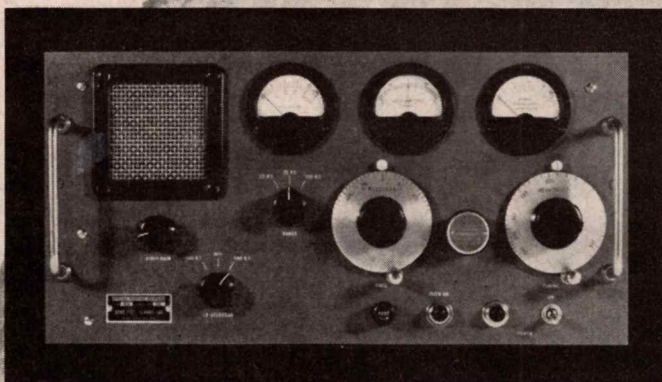


FORD ENGINEER checking voltage and frequency accuracy of power supply unit under simulated load conditions in a project for the Guided Missile Development Division of the Redstone Arsenal.

121

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The Type 1400 is the first receiver designed specifically for telemetry applications to employ crystal control, extremely high adjacent-channel attenuation, and two separate IF channels. One channel is specifically designed for FM/FM telemetry, the other for PWM/FM systems. From the standpoint of selectivity, noise figure, distortion and stability it represents an outstanding advance. The specifications were written with the cooperation of the engineering staffs of the important missile test facilities of all the military services.

SPECIFICATIONS

Frequency Range.....	216-245 Megacycles determined by plug in crystals.
Input Impedance.....	50 ohms nominal.
Noise Figure.....	Less than 7 db.
Tuning.....	Tunable over a frequency range ± 150 KC's.
IF Bandwidth.....	Wide band—500 KC bandwidth at 3 db points. Attenuation ± 500 KC from center frequency greater than 60 db. Narrow band—100 KC bandwidth at 3 db points. Attenuation ± 250 KC from center frequency greater than 60 db.
Signal to Noise Ratio.....	500 KC Passband. S/N ratio is 40 db for 2 uv of input carrier when carrier is modulated ± 100 KC at a 1000 CPS rate. 100 KC Passband. S/N ratio is 40 db for 1.5 uv of input carrier when carrier is modulated ± 50 KC at a 1000 CPS rate. The above S/N ratios are measured with a 2500 CPS RC lowpass filter at the receiving video output.
Panadaptor Output.....	Provision for connecting into a 30 MC panadaptor.
Frequency Deviation Meter.....	Peak reading over frequency range from 400 to 80,000 CPS. Three scales 25, 75 and 150 KC.
External Field Strength Meter.....	Output 10 milliamperes into 500 ohm load.
Size.....	8 $\frac{3}{4}$ " x 19" x 15 $\frac{3}{4}$ ".
Weight.....	Approximately 40 lbs.
Power Input.....	117v AC, 60 Cycles, Approximately 150 Watts.

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trol bearings for aircraft, which come in five sizes. The Fafnir Bearing Company says every member of the series is specifically designed so that bearing capacity, shank and bolt strength are in balance. (T-36)

Basaltwool. Bulletin describes new fiber heat and sound insulating material which withstands 1450°F, extreme vibration and high air velocities, according to Thermo-Sound Products, Division of Kittell-Lacy, Inc. Graphs present procedures and results of basaltwool tests. (T-37)

Colloidal and Semi-Colloidal Dispersion. 4 pp booklet lists 41 colloidal and semi-colloidal dispersions for numerous industrial applications. Products include dispersions of graphite, molybdenum disulfide, mica, vermiculite, zinc oxide and acetylene black. Carriers and diluents are given for each product, along with typical applications and important physical data. Acheson Colloids Company. (T-38)

Beryllium Copper Springs. 4 pp technical bulletin No. 33 describes use of Berylco beryllium copper as heart of new vibration damping device for mounting electronic components in aircraft. Includes complete data on metal requirements for Berylco alloy wire mesh springs, as well as design and fabrication considerations. The Beryllium Corporation. (T-39)

Temperature Test Chamber. 6 pp illustrated bulletin gives operating principle and procedure of new Model TC-2A temperature test chamber and lists complete specifications as well as all maintenance information. Statham Development Corporation. (T-40)

Vibration Calibrator. Technical bulletin 501 discusses features of Model 501 vibration calibrator and gives specifications. Instrument is designed to calibrate vibration pick-ups or to measure vibration of non-magnetic, metallic surfaces. Uses new method of self-calibration whereby vibratory displacements are compared with a precise standard displacement. ACF Electronics, Division of ACF Industries, Incorporated. (T-41)

High Pressure Air Equipment. Data sheets describe ACE-35 mobile high pressure air stand and ACE-37 high pressure bottle cart. Accessory Controls & Equipment Corp. says these units are presently being used by aircraft industry for high pressure testing of landing gear mechanisms and other components, as well as starting of jet aircraft. (T-42)

Molybdenum Carbides and Nitrides. 6 pp bulletin Cbd-7 summarizes applications; physical, chemical and mechanical properties; and preparation of molybdenum carbides and nitrides. These refractory materials have been used or appear to have potential value in cutting tools, thermocouple protection tubes, contacts in circuit breakers and such hard-surfacing applications as shot-blasting nozzles, bearing sur-

faces and die facings, according to Climax Molybdenum Company. (T-43)

Hipot Testers. Catalog describes "H" series of sensitive hipot testers for production and over-voltage testing and for preventive maintenance on electrical equipment. Peschel Electronics Inc. claims the high sensitivity shows up leakage currents in insulation which appear to be perfect in less sensitive instruments. (T-44)

Bearings. 31 pp booklet discusses various types of bearings and gives numerous diagrams and tables. Includes many tables on load ratings and a list of metric equivalents (mm to in.) up to 300 mm, in addition to table on decimal equivalents of parts of an inch. Industrial Tectonics, Inc. (T-45)

Electrophotographic Recording Oscillograph. Bulletin CGC-311 gives data on Model 420, which offers 24 trace lightbeam recording on electrosensitive paper with automatic sensitizing, dry developing and fixing. Without darkroom facilities, produces 8 in. wide oscillograms that may be read instantly after recording, according to Century Electronics & Instruments, Inc. (T-46)

Stainless Tubular Products. 4 pp folder, TDC-182, furnishes information about various machining operations on stainless pipe and tubing. Tooling, power requirements, cutting oils and finishing are briefly discussed, along with machining operations. Babcock & Wilcox Company, Tubular Products Division. (T-47)

Wire Strippers. 4 pp brochure gives technical features, application and operational procedure of new chemical wire strippers for stripping insulation from armature and coil leads. London Chemical Company, Inc. (T-48)

Curve Follower. Data sheet discusses SF-1 curve follower, which was especially developed as an input function generator for programming simulated aerodynamic heating tests. Alabama Automation Corporation. (T-49)

Cored Forgings. 6 pp brochure describes Weatherhead Company cored forgings in aluminum and other non-ferrous metals. Forgings may be cored four ways in the same plane, making unusual shapes possible. Aviation Division. (T-50)

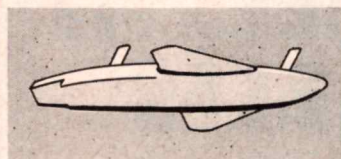
Apcotite. 8 pp brochure covers bonding of natural and synthetic rubber, and silicone to metal. Features new rating chart showing latest materials that can be successfully bonded to various polymers. Acushnet Process Company. (T-51)

Tandem Transistor. 4 pp bulletin contains illustrations of fundamental circuitry, description, applications, rating, cut-off frequency, electrical data, maximum ratings and tandem parameters of new tandem transistor

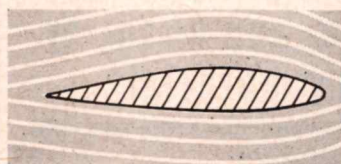


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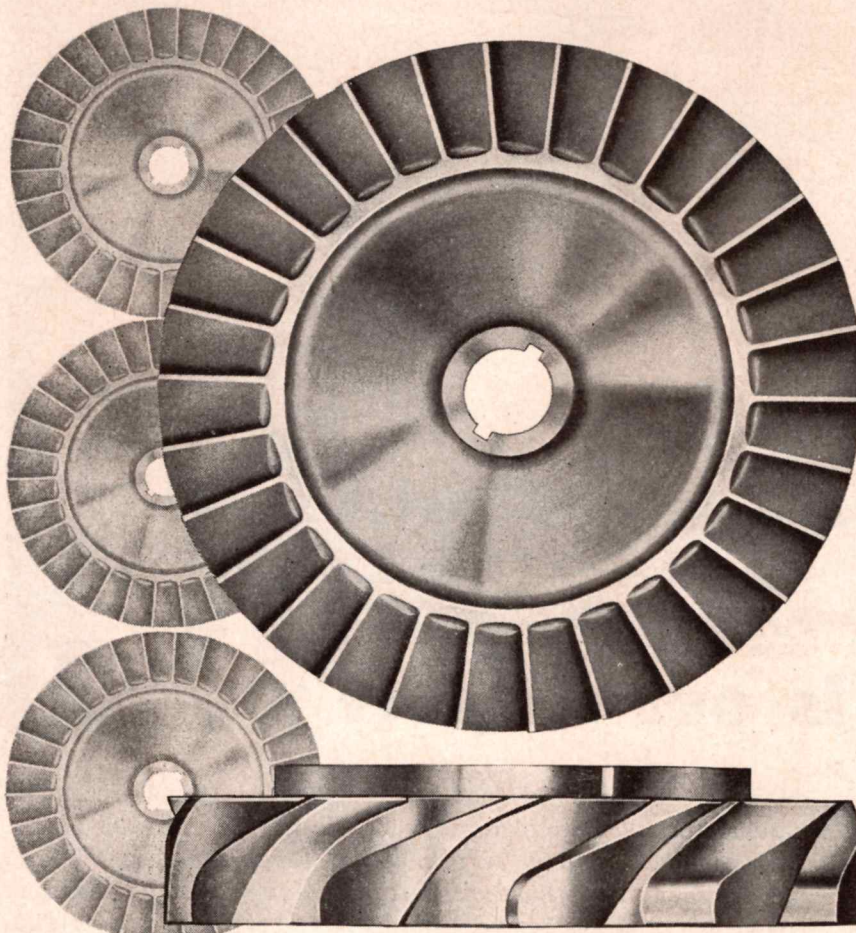
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offered by Marvelco Electronics Division of National Aircraft Corporation. (T-52)

Synchros, Servo Motors and Resolvers. Norden-Ketay's bulletin 376 gives characteristics of over 138 synchros, servo motors and resolvers. Intended to provide engineers with an easy guide for the selection of rotating components. (T-53)

Voltage Regulators. Illustrated data sheet presents three types of voltage regulators built to military standards for 30 kw engine-driven alternators. Arga Division, Beckman Instruments, Inc. (T-54)

Protective Coatings, Industrial Adhesives. Newly-revised catalog gives technical data concerning properties of Magic Chemical Company's protective coating and industrial adhesives. (T-55)

Shock Absorbers. Catalog LS describes and illustrates complete line of Taylor liquid springs designed especially for replacing coil springs in die applications using liquid compressibility. According to manufacturer, one Taylor liquid spring delivers same total end force as 10 heavy-duty standard die springs of same size. Taylor Devices Incorporated. (T-56)

Microwave Components. 12 pp catalog C-356 covers complete line of E and H plane bends and top wall and side wall hybrid junctions now made available by Microwave Development Laboratories. (T-57)

Gas Carburizing. 8 pp booklet discusses method of adding carbon to ferrous alloys and details equipment necessary for process. Surface Combustion Corporation. (T-58)

Temperature Cabinets. 4 pp bulletin gives data on line of temperature cabinets from 1 cu ft to 45 cu ft with ranges from -200°F to $+300^{\circ}\text{F}$. Temperatures are controlled in accuracy to $\pm 0.2^{\circ}\text{F}$. Webber Engineering Corporation. (T-59)

Glass Cloth for Drafting. Reference manual tells how glass cloth for drafting and reproduction can safely be used on much larger scale and attempts to show how coordination with sub-contractors can be improved. Tru-scale, Inc. (T-60)

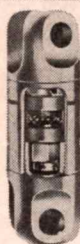
Filter Design. 4 pp catalog MK-170 describes simplified filter for diesel fuel and lube, pipelines, process liquids, water, gasoline and aviation fuels. Includes specifications, flow rates and engineering drawings. The Cuno Engineering Corporation. (T-61)

Identicharts. 4 pp illustrated bulletin tells story of automatic devices that print identifying marks on strip charts from a remote point to show the time or in what sequence conditions occur during process, test or control work. Available in easy-to-install kit form, mechanisms do not interfere with or obscure recording procedure and operate on any a-c or d-c voltage from 24 to 110 v. Royson Engineering Company. (T-62)

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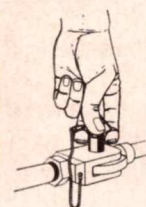
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CREEP AND FRACTURE OF METALS AT HIGH TEMPERATURES, Proceedings of a symposium held at the National Physical Laboratory, May 31-June 2, 1954, published in London, 1956, American Agents: British Information Services, 30 Rockefeller Plaza, New York. 420 pp, \$5.60.

Twenty-two papers divided into four categories of interest were presented at the symposium. The categories are: deformation processes in simple materials, creep resistance of complex materials, theory of fracture, and work on tertiary creep and fracture. Much valuable engineering data and charts are included in this published work.

Circle Reader Reply No. 90

THE THEORY OF SOUND, 2 volumes, Lord Rayleigh, second edition revised and enlarged, Dover Publications, New York. Vol. 1, 480 pp, paper

bound, \$1.95. Vol. 2, 504 pp, paper bound, \$1.95.

This book was the major work of Lord Rayleigh, one of the outstanding 19th century physicists. It is a standard work of classical physics, which has served generations of scientists. It is an enormous treatise covering almost all aspects of sound. Not merely a reference work, it is a work of great value to physicists, mathematicians and engineers interested in pure and applied aspects of sound, acoustics, conduction, vibration, vibratory geophysics and insulation.

Circle Reader Reply No. 91

THE AIR FORCE, Arnold Brophy, 1956, Gilbert Press, New York. 362 pp, \$5.

Here is a detailed picture of the United States Air Force—how it was born, how it grew up, and what it is

today. It includes an account of all the commands in the Air Force, their functions in peace and war, the planes and equipment they use, and the men involved.

Circle Reader Reply No. 92

WORLD AIRCRAFT RECOGNITION MANUAL, C. H. Gibbs-Smith and L. E. Bradford, John de Graff, New York. 269 pp, \$3.50.

This is a new approach to aircraft recognition and classification, in which aircraft are arranged under the general headings of delta-wing, swept-wing, straight-wing, etc., and grouped within these sections by similarities in plan view, engine distribution and so forth. By this arrangement, rapid identification of every type aircraft is simplified. In addition, the book provides data on over 240 civilian and military aircraft.

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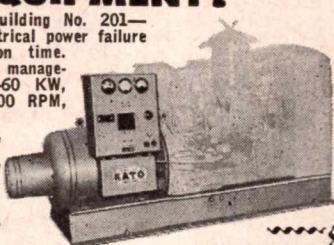
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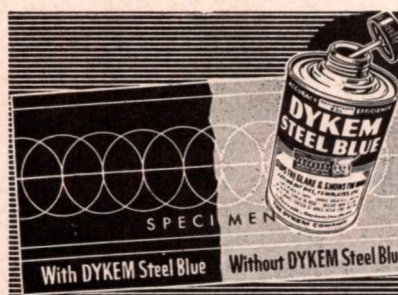
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abstracts

Robert J. Tapscott and F. B. Gustafson, METHODS OF PREDICTING HELICOPTER STABILITY, NACA RM L54G05, November 1954.

Some of the methods of predicting rotor stability derivatives have been reviewed. The methods by which these rotor derivatives are employed to estimate helicopter stability characteristics have been summarized. It is concluded that, although these methods are not always feasible for predicting absolute values of the stability of the helicopter, the effects on stability of changes in individual derivatives can generally be estimated satisfactorily.

Robert H. Heitkotter, THE DESIGN OF A MINIATURE SOLID-PROPELLANT ROCKET, NACA TN 3620, March 1956.

A miniature rocket motor was designed and developed to exert 3 ounces of thrust for a duration of 2 seconds. The rocket has reproducible performance and is simply constructed. The research that led to the development of the miniature rocket showed that compensatory measures must be used in designing extremely small rockets because of excessive heat-transfer rates.

A. Gerald Rainey, PRELIMINARY STUDY OF SOME FACTORS WHICH AFFECT THE STALL-FLUTTER CHARACTERISTICS OF THIN WINGS, NACA TN 3622, March 1956.

The results of an exploratory, analytical, and experimental study of some of the factors which might be of importance in the stall flutter of thin wings are presented. The factors considered were Mach number, Reynolds number, density, aspect ratio, sweepback, structural damping, location of torsion nodal line, and concentrated weights.

W. G. Rowell and A. B. Van Rennes, NEW CONCEPT IN FAIL-SAFE SYSTEM DESIGN, Technical Information Bulletin, Scully Signal Company, Electronics Division, Melrose, Massachusetts.

A new technique for monitoring the output of any operating system also serves to check the monitoring system itself.

Operation is completely fail-safe, and failure in the performance of either operating or monitoring system will cause appropriate warning or corrective action to be taken. In essence, the monitoring system is subjected to a periodic checking signal which modulates the normal, or safe, operating condition of the monitoring system. Failure of either the operating system or the monitoring system halts the required oscillation, and sounds the alarm or initiates corrective action. Duplication and triplication of critical components is no longer required. Completely reliable automatic circuit checking now makes possible infallible "fail-safe" operation of circuits and control systems.

Dean T. Bowden, EFFECT OF PNEUMATIC DE-ICERS AND ICE FORMATIONS ON AERODYNAMIC CHARACTERISTICS OF AN AIRFOIL, NACA TN 3564, February 1956.

Measurements of drag, lift, and pitching moment of an NACA 0011 airfoil were made in icing conditions using pneumatic de-icers having either spanwise or chordwise inflatable tubes. Lift and drag penalties due to de-icer inflation and to ice remaining after de-icer inflation are presented. Inflation of the spanwise-tube de-icer caused a much greater increase in drag than inflation of the chordwise-tube de-icer. The two de-icers were equally effective in removing ice. Lift and drag penalties resulting from ice formed with the de-icer inoperative are also presented, as well as spoiler data for analyzing drag increases due to ice formations.

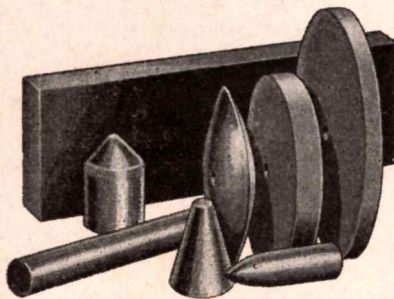
Robert L. Johnson, Max A. Swikert and John M. Bailey, WEAR OF TYPICAL CARBON-BASE SLIDING SEAL MATERIALS AT TEMPERATURES TO 700° F, NACA TN 3595, February 1956.

Wear and friction studies were made with carbon-type seal materials sliding against tool steel, stainless steel and chromium-plated steel at temperatures to 700° F and a sliding velocity of 10,000 fpm. Wear was several times greater at 500° F and above than with no heat added for all carbon materials. The mating material had more effect on wear and surface failure than did the use of various impregnants in the carbon. Chromium plate gave less wear than the other mating materials under all conditions of the experiment.

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Silicon - What It Is and What It Does in Alloy Steels

Silicon is a very abundant non-metallic element, one of the chief elementary constituents of the earth's crust. In the form of ferro-silicon, it is used by steelmakers as a deoxidizer and hardener in both alloy and carbon steels.

When the maximum silicon content is specified within the limits of 0.60 to 2.20 pct, the resulting steel is classed as a silicon alloy steel. However, all other standard alloy grades are specified to a range of 0.20 to 0.35 silicon for purposes of deoxidation. Silicon has several interesting effects, among them three that should be noted carefully: (1) it raises the critical temperature for heat-treatment; (2) as the amount is increased, it increases the susceptibility of steel to decarburization and graphitization; (3) combined with other alloying elements such as nickel, chromium, and tungsten, it promotes resistance to high temperature oxidation.

Silicon-Manganese Steels

Of the alloy steels relying heavily on silicon, one of the most important groups is the silicon-manganese series. As mentioned above, silicon is recognized as a deoxidizing agent, and a powerful one. Manganese behaves in the same manner but to a lesser degree.

Manganese exerts beneficial effects on the mechanical properties of heat-treated steel. Silicon as an

alloy increases the strength. A properly balanced combination of the two elements produces a steel with unusually high strength, and with good ductility and shock-resistance.

Silicon-manganese steel has been widely used for the making of coil and leaf-type springs. It has also been used successfully for chisels, drift pins, punches, shear blades, mine bits, and other products that must be shock-resistant. It responds readily to oil-quenching, and when tempered at the correct temperature, it possesses not only shock-resistance but toughness and strength.

We invite you to consult with Bethlehem metallurgists whenever you wish to know more about silicon and its uses in steel. If you care to have them do so, these technicians will gladly suggest the proper analysis for your particular needs. Whatever it is, Bethlehem can furnish it, for Bethlehem makes all AISI standard alloy steels, as well as special-analysis steels and the full range of carbon grades.

If you would like to have a reprint of this advertisement, or of the entire series from I through XIV, please write to us, addressing your request to Publications Dept., Bethlehem Steel Company, Bethlehem, Pa.

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BETHLEHEM STEEL

MISSILES FOR PEACE?

ON THIS PAGE a year ago, Dr. Theodore von Karman, Chairman of the NATO Advisory Group on Research and Development and one of America's leading scientists, previewed the role of guided missiles in modern society, and their relationship to aeronautical development generally.

A pioneer aerodynamacist, Dr. von Karman is also a pioneer in social thinking. The crux of his editorial made national headlines. Missiles, he said, could have an important role in peacetime applications hauling mail and cargoes, and there was a possible future in astronautics as a practical industry. In the meantime, work of scientists in both fields would unquestionably advance the whole realm of aviation progress.

During the ensuing year, remarkable progress has been made toward proving these statements true. Hall L. Hibbard of Lockheed states flatly that wingless ballistic missiles will be used for commercial purposes in the future. The near-reality earth satellite will improve navigation, communications, meteorology and weather predictions. As a result of present research and development in advanced fields, he also sees in your future a twinjet family type convertiplane which can be landed in a driveway and driven like an automobile.

With this equipment on the horizon, demands will appear to put them to work. President Eisenhower's recent proposal that the American university campus be extended to the corners of the earth can operate efficiently only with air transport linking the scattered units. Rocket freighters can only increase that efficiency. There is no limit to peacetime applications of all things aeronautical, assuming a reasonable amount of investment in time and capital to perfect the vehicles in question.

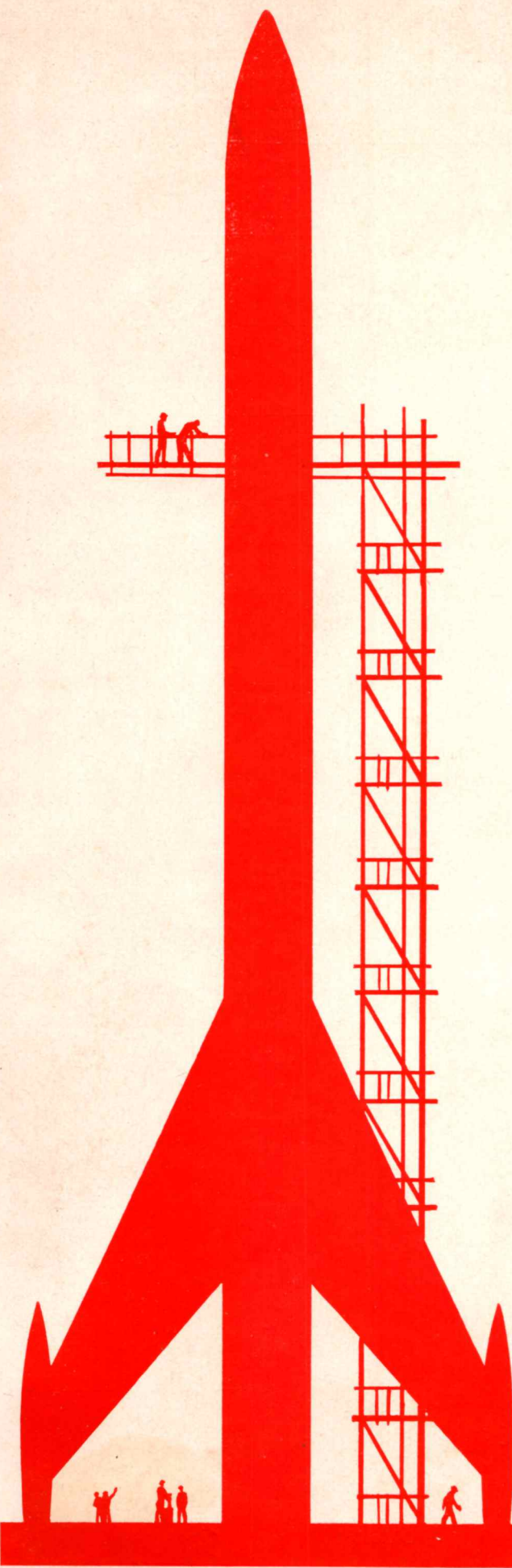
Historically, that society with the most advanced transportation has dominated civilization. If the dominance was strong enough, eras of peace resulted. Rome reduced wars to a minimum with its monopoly of roads, Britain with its ships. With the peace came dramatic eras of prosperity and progress.

That we should push aerial research and development to the limit is therefore not a matter of necessity, but of common sense as a sound investment in the future. Large national budgets for air should be as standard, war or peace, as budgeting for maintaining our rivers and harbors. They should be determined with the premise that they will give a stability to the aviation industry in all its aspects, which will enable it to go forward, under a programmed economy, with the greatest of speed.

Under such a program, the current talk of arms cuts would strike no fear in the minds of those now making a career of aviation. Their jobs would be assured, regardless of whether we are building bombers or transports, atom rockets or atom freighters.

It is a program that is made to order for American enterprise, which has never been challenged in its supremacy in the field of peacetime use of aviation for the national—and international—welfare.

—FRED HAMLIN



DESTINATION...

UNKNOWN!

Rockets to points in outer space! They are more than a dream. In fact, some morning before long you may wake up to find such rockets a reality.

Right now, AC engineers, together with some of America's top scientists, are hard at work developing electro-mechanical guidance systems that are capable of directing missiles to many points in outer space.

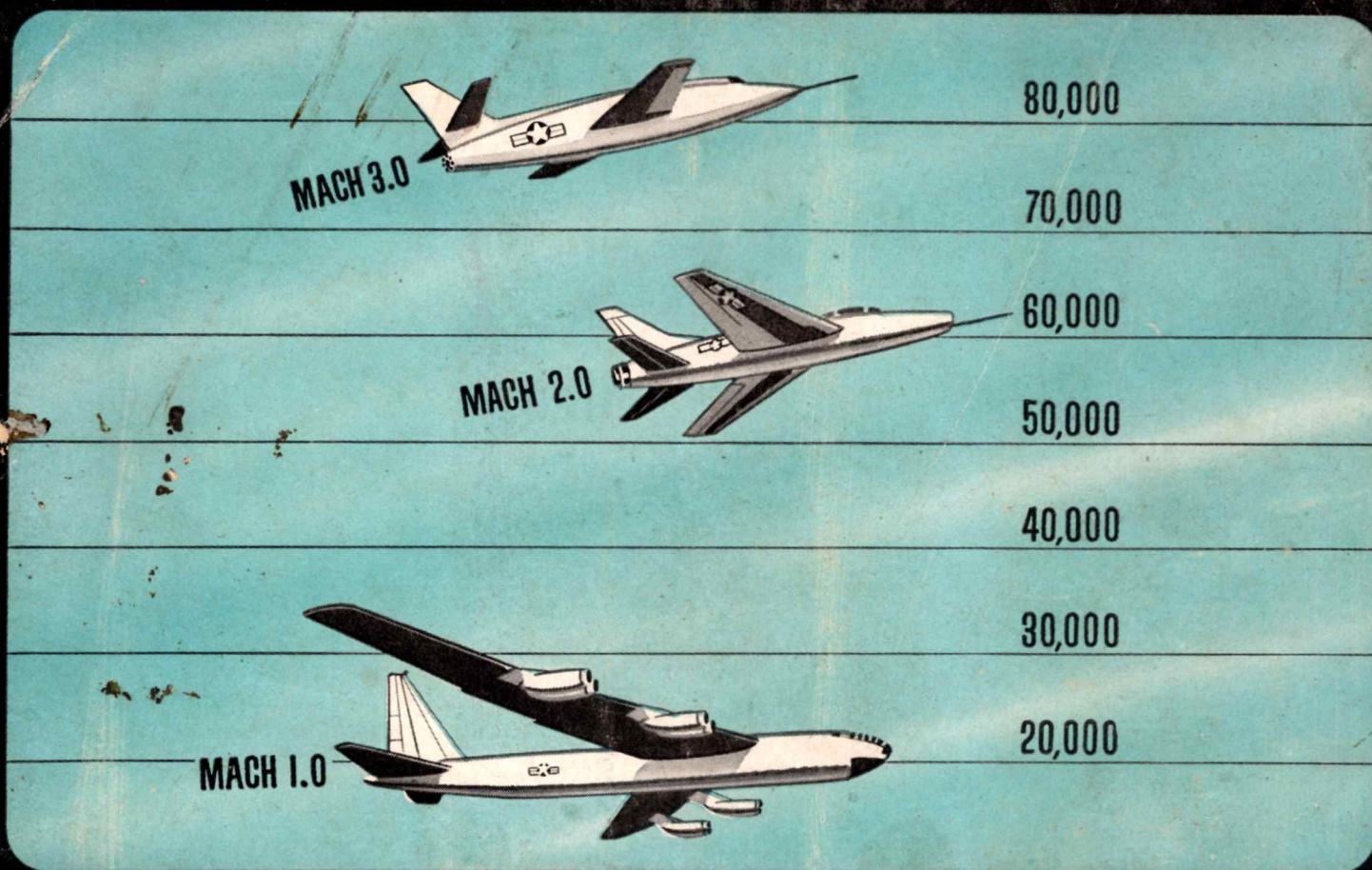
Fantastic? Not at all. AC has built a world-wide reputation with outstanding contributions in the fields of guidance, navigation and fire control.

AC is well on the way to development of control systems that can direct space-rockets on their way.



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The new Bendix system consists of a single computer with interchangeable converters. This design permits operation over a wider range of speed and altitude than ever before possible with one instrument. And it provides a flexibility that will give many desired combinations of outputs for any aircraft of today or the predictable future.

Here's an end to duplicate computations previously required to supply different systems on the same aircraft! Here's an end to multiple types of computers, each tailor-made to aircraft having different flight characteristics!

Among the many advantages of the new Bendix Central Air

Data Computer System are: *Universal application within a wide range of operational limits • Increased reliability through use of transistors and mechanical computers • Duplicate equipment replaced by a single coordinated computing mechanism • Unlimited number and types of outputs • Simplified correction for pressure probe position error.*

We believe we have the answers you have been looking for and would like to discuss them with you. ECLIPSE-PIONEER DIVISION, BENDIX AVIATION CORPORATION, TETERBORO, N.J.

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